TM-85250

E83-10318

FY 1982

AgRISTARS

RESEARCH REPORT

(E83-10318) AGRISTARS: AGRICULTURE AND RESOURCES INVENTORY SURVEYS THROUGH AEROSPACE REMOTE SENSING, RESEARCH REPORT, FISCAL YEAR 1982 (NASA) 85 p HC A05/MF A01 CSCL 02C N83-28504 Unclas G3/43 00318

A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

AP-J2-0393

AgRISTARS

AGRICULTURE AND RESOURCES INVENTORY SURVEYS THROUGH AEROSPACE REMOTE SENSING

RESEARCH REPORT - FISCAL YEAR 1982

Prepared by

AgRISTARS Program Management Group

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

January 1983

PREFACE

The AgRISTARS program was initiated in fiscal year 1980 in response to an initiative issued by the U.S. Department of Agriculture. Led by the USDA, the program is a cooperative effort with the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, the U.S. Department of the Interior, and the Agency for International Development of the U.S. Department of State.

The program goal is to determine the usefulness, cost, and extent to which aerospace remote sensing data can be integrated into existing or future USDA systems to improve the objectivity, reliability, timeliness, and adequacy of information required to carry out USDA missions.

The program is well underway, with encouraging progress having been made in fiscal years 1980*, 1981**, and 1982 (as documented in this report). The outlook is that aerospace remote sensing will contribute to USDA information needs in a significant way and, more generally, that the AgRISTARS effort will advance this technology for use in other areas of national need.

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*AgRISTARS Annual Report - Fiscal Year 1980; AP-J0-04111, National Aeronautics and Space Administration (NASA), Lyndon B. Johnson Space Center (JSC), June 1981.

**AgRISTARS Annual Report - Fiscal Year 1981; AP-J2-04225, NASA-JSC, January 1982.

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FIGURES

ACRONYMS

AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
agromet	agricultural-meteorological
AID	Agency for International Development
APEP	Advanced Proportion Estimation Procedure
APU	agrophysical unit
ARS	Agricultural Research Service
ASMA	Automatic Segment-to-Map Algorithm
AVHRR	advanced very high resolution radiometer
AVI	Ashburn vegetative index
CCT	computer-compatible tape
CEAS	Center for Environmental Assessment Services
CMI	crop moisture index
C/P	Conservation and Pollution
CPU	computer processing unit
CRD	Crop Reporting District
CWSI	crop water stress index
DC/LC	Domestic Crops and Land Cover
EDIS	Environmental Data and Information Service
ESC	Earth Satellite Corporation
EW/CCA	Early Warning and Crop Condition Assessment
FAS	Foreign Agricultural Service
FY	fiscal year
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
GSS	Ground Scatterometer System
ICC	Interagency Coordinating Committee
IPB	Interagency Policy Board
ITD	Inventory Technology Development
JES	June Enumerative Survey
JPL	Jet Propulsion Laboratory
JSC	Lyndon B. Johnson Space Center

LACIE	Large Area Crop Inventory Experiment
LAI	leaf area index
MDP	master data processor
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
NESS	National Environmental Satellite Service
NOAA	National Oceanic and Atmospheric Administration
NWSRFS	National Weather Service River Forecast System
pixel	picture element
PMT	Program Management Team
PSS	Program Support Staff
RMSE	root mean square error
RRI	Renewable Resources Inventory
SAR	synthetic aperture radar
SAS	Statistical Analysis System
SCS	Soil Conservation Service
SIR	Shuttle Imaging Radar
SM	Soil Moisture
SMMR	Scanning Multichannel Microwave Radiometer
S/N	signal-to-noise
SR	Supporting Research
SRS	Statistical Reporting Service
TAMW	Texas A&M wheat model
TM	Thematic Mapper
TMS	Thematic mapper simulator
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of the Interior
USSG	U.S. Geological Survey
VIN	vegetaline index number
YMD	Yield Model Development

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I. PURPOSE

The purpose of this report is to present the major objectives and accomplishments of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program and its eight component projects during fiscal year (FY) 1982.

The report includes an introduction to the overall AgRISTARS program, a general statement on progress, and separate summaries of the activities of each project, with emphasis on the technical highlights. It is planned to issue similar research reports around January of each year. Organizational and management information on AgRISTARS is included in the appendixes, as is a complete bibliography of publications and reports. Additional information may be obtained from:

AgRISTARS Program Management Group
Code SK
NASA-Lyndon B. Johnson Space Center
Houston, Texas 77058
Telephone: 713-483-2548
(FTS: 525-2548)

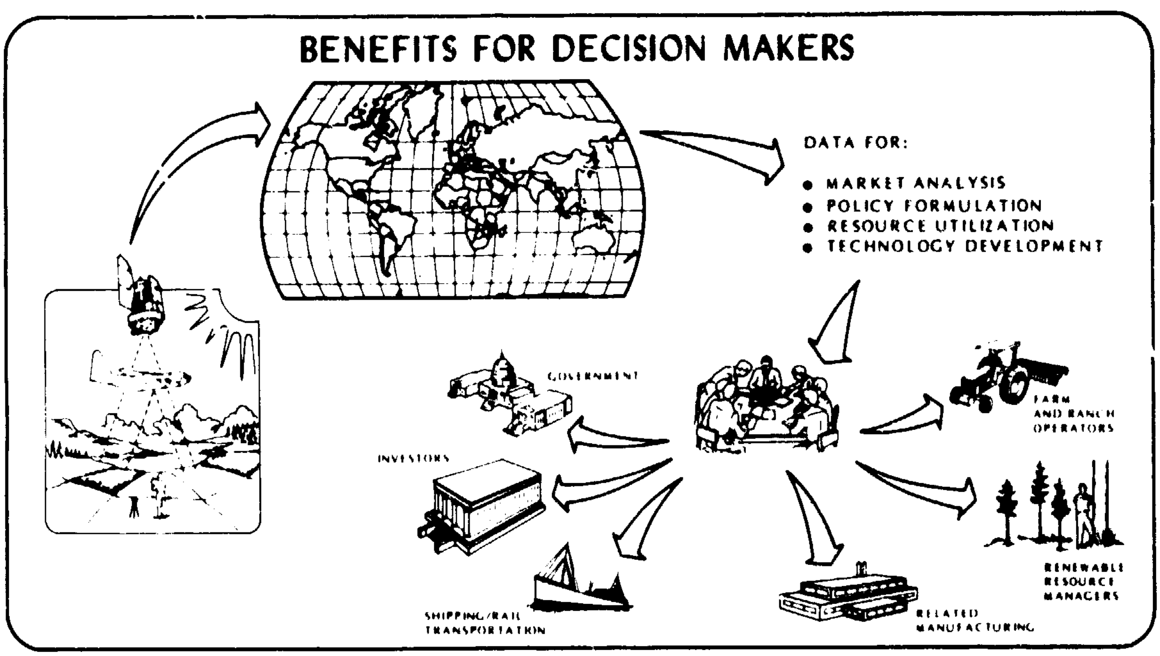
Inventory Surveys Through
AgRISTARS
Agriculture and Resources
Aerospace Remote Sensing
USDA NASA USDC USDI AID

2. INTRODUCTION

AgRISTARS is a long-term program of research, development, test, and evaluation of aerospace remote sensing to meet the needs of the U.S. Department of Agriculture (USDA). The program is a cooperative effort of: the USDA; the National Aeronautics and Space Administration (NASA); the U.S. Department of Commerce (USDC) through the National Oceanic and Atmospheric Administration (NOAA); and the U.S. Department of the Interior (USDI). In addition, the Agency for International Development (AID) participates as an ex officio observer and potential future user agency.

In 1978, the Secretary of Agriculture issued an initiative,[1] in response to which the participating agencies established the AgRISTARS program. In 1980, the program was initiated as an effort based on satisfying current and future requirements of the USDA for high-priority agricultural and other renewable resources type information. This information is important to the USDA in addressing national and international issues on supply, demand, and competition for food and fiber.

[1] Joint Program of Research and Development of Uses of Aerospace Technology for Agricultural Programs, February 1978.



Remote sensing technology is being developed to give timely, reliable information to those concerned with the worldwide status of renewable resources.

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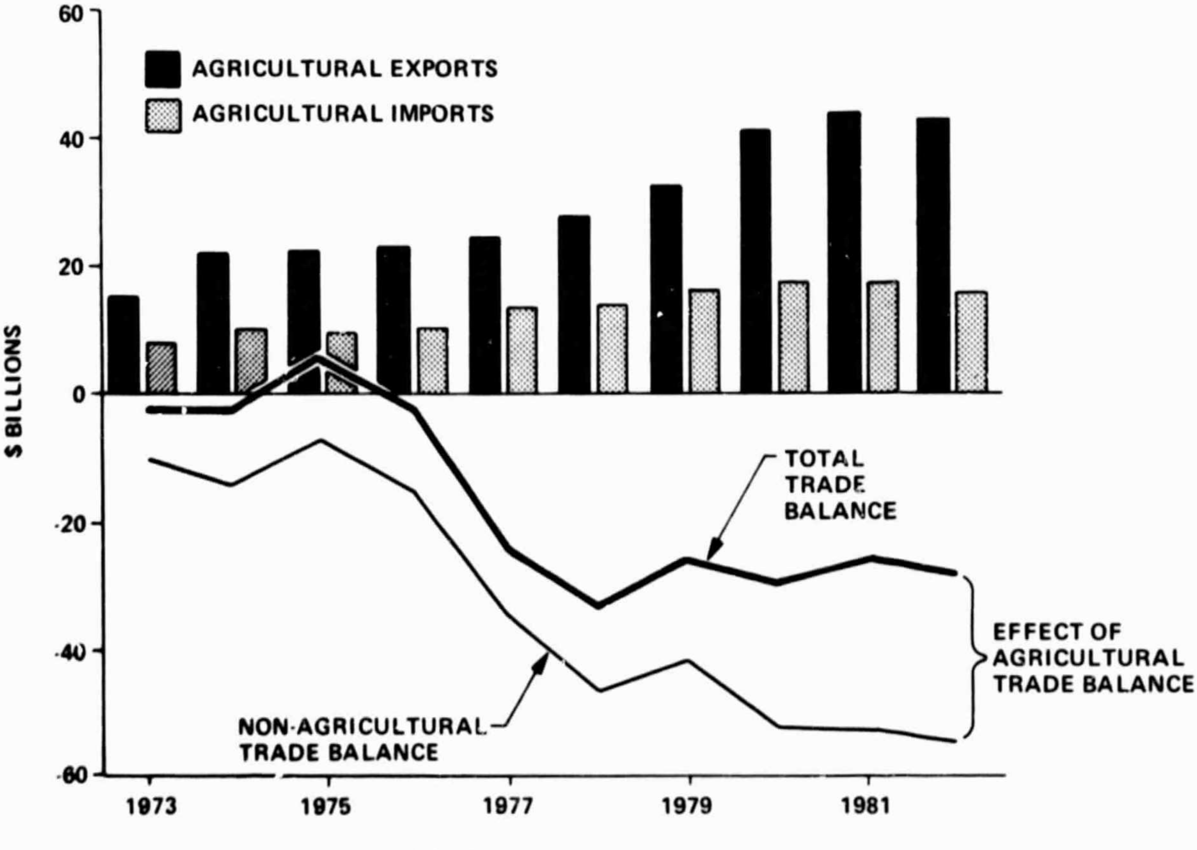
The overall goal of AgRISTARS is to determine the feasibility of integrating aerospace remote sensing technology into existing or future USDA data acquisition systems. Determining feasibility depends upon the assessment of numerous factors over an extended period of time. Determinations of the reliability, costs, timeliness, objectivity, and adequacy of information required to carry out USDA missions are planned in the program. The overall approach consists of a balanced program of remote sensing research, development, and testing which addresses a wide range of information needs on domestic and global resources and agricultural commodities.

In this initiative, the USDA identified the following seven information requirements:

- Early warning of change affecting production and quality of commodities and renewable resources
- Commodity production forecasts
- Land use classification and measurement
- Renewable resources inventory and assessment
- Land productivity estimates

U.S. TRADE BALANCE



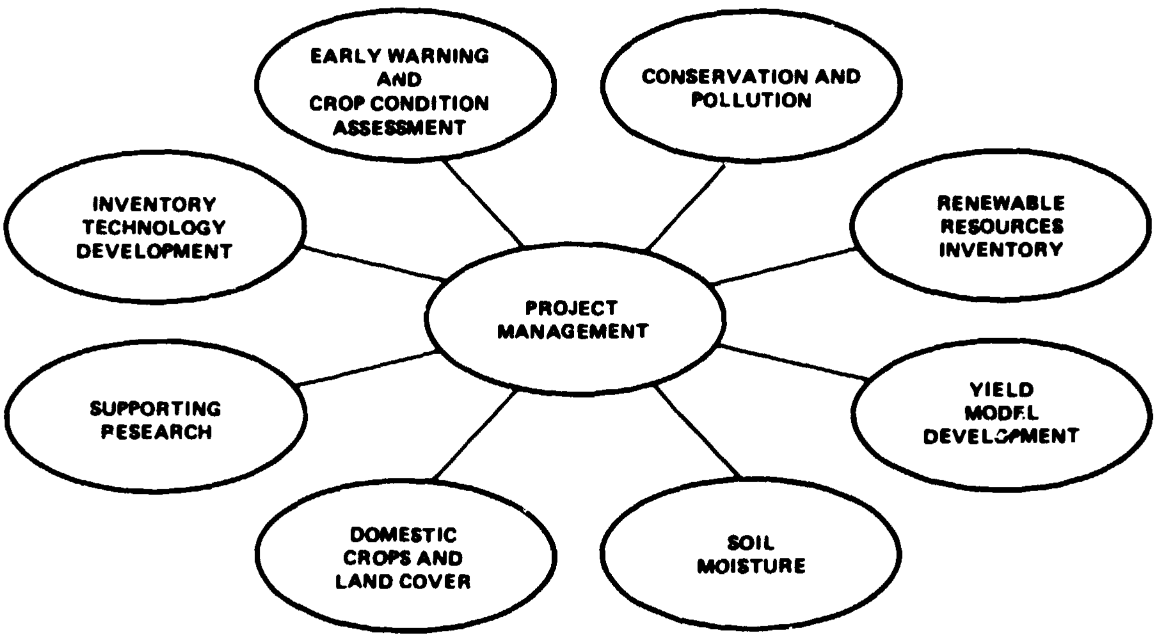
- Conservation practices assessment
- Pollution detection and impact evaluations

Based on these information requirements, as well as on a specific immediate need for better or more timely information on crop conditions and expected production, the AgRISTARS technical program was developed. It consists of eight projects which address all seven of the USDA information needs with a clear emphasis on the first two, early warning of change and commodity production forecasts. The eight projects include the following:

- Early Warning and Crop Condition Assessment (EW/CCA)
- Inventory Technology Development (ITD)
- Yield Model Development (YMD)
- Supporting Research (SR)
- Soil Moisture (SM)
- Domestic Crops and Land Cover (DC/LC)
- Renewable Resources Inventory (RRI)
- Conservation and Pollution (C/P)

Each project has its specific set of objectives and is treated in this report as a discrete element of the AgRISTARS program. The projects are interrelated both through mutuality of data needs and through much common technology.

AgRISTARS PROJECTS



3. PROGRAM SUMMARY

The AgRISTARS program has been underway for 3 years, and substantial progress has been made on a number of fronts.

The USDA, as the prime user of the technology being developed, has been actively involved and has continued to view the effort as one of importance.

The technical accomplishments of greatest note in FY 1982 were:

- A highly automated technique for classifying corn and soybeans near harvest was successfully tested over large areas of the U.S. Corn Belt.
- An automated technique to estimate the area of spring small grains early in the season (within 1 month of planting) was successfully tested over the U. S. Northern Great Plains with comparable accuracy to earlier end-of-season results. The technology has been implemented by the USDA Foreign Agricultural Service (FAS).
- Analysis of Thematic Mapper simulator (TMS) data over various types of forests indicated a high level of accuracy in delineating major forest types.
- The development of models to provide alarms of potentially damaging conditions (e.g., drought and temperature stress and disease epidemics) have made substantial progress.
- Domestic crop estimation, utilitizing Landsat data, is now implemented or being implemented in five states.
- Combining TMS and synthetic aperture radar (SAR) data showed improved accuracy in distinguishing crop and land cover classes.
- The State of California has modified its forest management policy, using Landsat technology from AgRISTARS.
- Investigations were made to determine the utility of satellite SAR for use in agricultural inventories. Investigations indicated: better definition of field boundaries; tone and texture features that can be used to improve crop labeling accuracies; and potential utility for more efficient sampling strategies, stratification, and precise sample unit location.
- Vegetation indices, developed in AgRISTARS, using meteorological satellite advanced very high resolution radiometer (AVHRR) data, are being utilized experimentally by the Agricultural Research Service (ARS).
- Microwave sensor response was shown to provide useful information on soil water profiles.
- Ozone damage to crops was shown to be detectable in the red region of the visible spectrum.

Under AgRISTARS, experiments are being conducted to determine the utility of the Thematic Mapper[2] (TM). The improved spectral and spatial capabilities of this new sensor are expected to improve greatly the remote sensing capability for satisfying AgRISTARS objectives. Figure 1 shows the comparison of the multispectral scanner (MSS) and TM spectral ranges. The increased number of spectral bands in the TM

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[2]Landsat-4, carrying the TM, was successfully launched into Sun-synchronous polar orbit on July 16, 1982.

provides the possibility of much greater information content. Figure 2 shows MSS and TM images over an agricultural area. The better spatial resolution with TM data is apparent in the sharper edges and improved field definitions. Initial analysis of data from the TM has verified that greatly improved agricultural information is contained in the data. Methods to extract the information show promise. Major indications to date are:

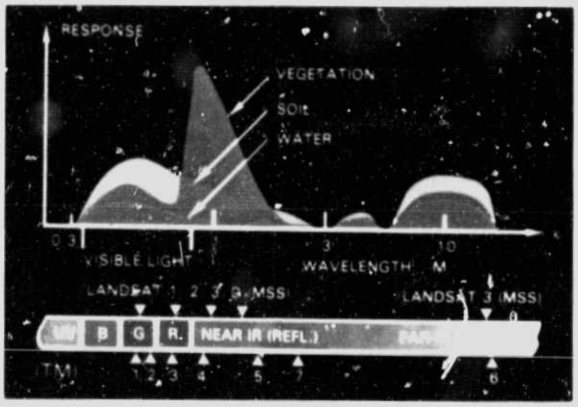


Figure 1.- Landsat Thematic Mapper (TM) and multispectral scanner (MSS) spectral bands versus typical Earth surface features. (The TM bands are more narrow and pr vide increased sensitivity.)

- The TM sensor and associated ground processing provided data that were well within advertised specifications.
- The data from the TMS were a good representation of TM data itself and, thus, provided for meaningful pre-TM studies.
- The improved precision in reduced bandwidths and the increased signal-to-noise (S/N) ratios exhibit new parameters for class separability cases that previously, with MSS, were available only with sophisticated technology using multitemporal analysis.

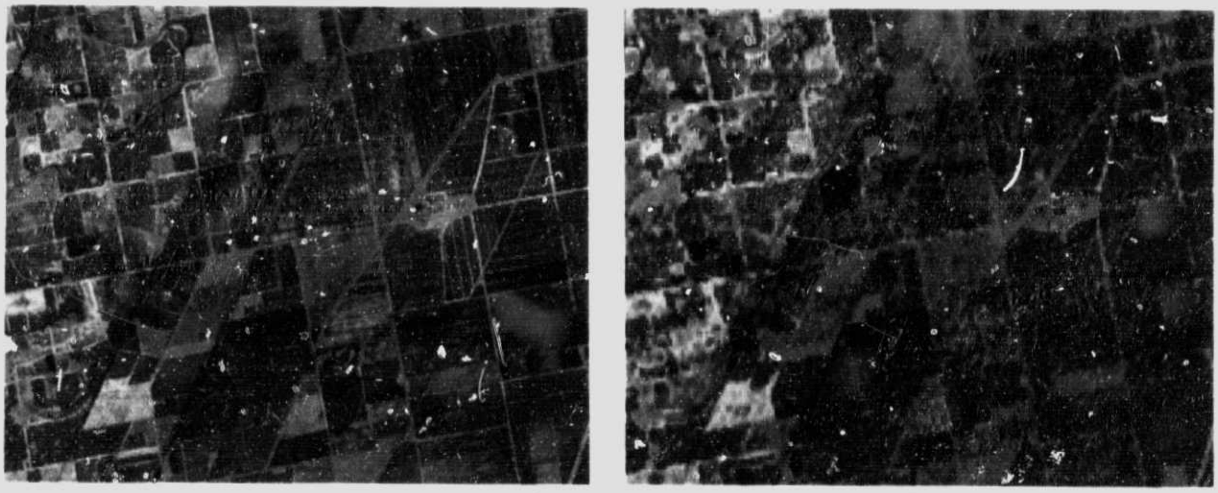


Figure 2.- Comparison of TM and MSS resolution. (The increased spatial resolution of the TM will allow more accurate crop identifications.)

4. PROJECT TECHNICAL HIGHLIGHTS

Technical highlights of the eight AgRISTARS projects are given in this section. Project overview, FY 1982 objectives, and accomplishments for the objectives are discussed.

4.1 EARLY WARNING/CROP CONDITION ASSESSMENT

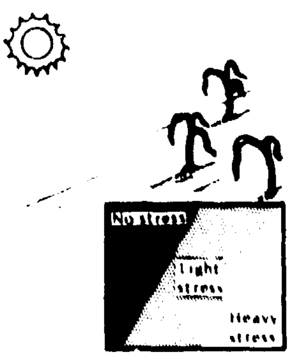
The EW/CCA research effort is designed to develop and test remote sensing techniques which will make possible or enhance operational methodologies for crop condition assessment. This technology will be used by elements of the USDA, in particular the FAS. The FAS is responsible for providing early warning of changes that may affect quantity and/or quality of crop production in foreign countries and for assessing crop conditions in general.

The EW/CCA project is managed by the USDA/ARS with participation by NASA, NOAA, and other USDA agencies. The project activity includes development of techniques for monitoring and assessing conditions that may impact crop production in both foreign and U.S. areas. Major commodities, for which technology is being developed, include: small grains (wheat and barley), corn, soybeans, sorghum, sunflowers, and cotton.

EARLY WARNING OF CONDITIONS AFFECTING CROPS

This project will assist the USDA in tracking the condition of major crops in the United States and foreign countries.

Techniques using data from satellites to measure the effects of drought on crops are well developed, and the areas of the crops affected can be accurately measured. Other types of crop stress are also being studied.



4.1.1 Technical Objectives

The particular technical objectives in FY 1982 were:

- To develop, test, and evaluate the use of meteorological and satellite data with various simulation models to provide timely alerts of abnormal and/or optimal conditions on a global basis.
- To provide improved definition of the relationships between plants and their environment and factors affecting the growth cycle.
- To determine and quantify relationships between crop stress and spectral response.
- To develop, test, and evaluate uses of NOAA-6 and NOAA-7 satellite data for indicating and monitoring abnormal conditions.

4.1.2 Alarm Models

Models were developed and/or improved to provide alarms when potentially damaging conditions occur. Conditions of drought and temperature stress were studied for wheat, corn, sorghum, sugar beets, and soybeans. These alarm models provide information on the status and tractability of preseason-stored soil water status, crop growth stage, and both hazardous and optimum moisture and temperature conditions that occur at various growth stages. Figure 3 illustrates the results of a test of the corn stress model which show a strong relationship between the

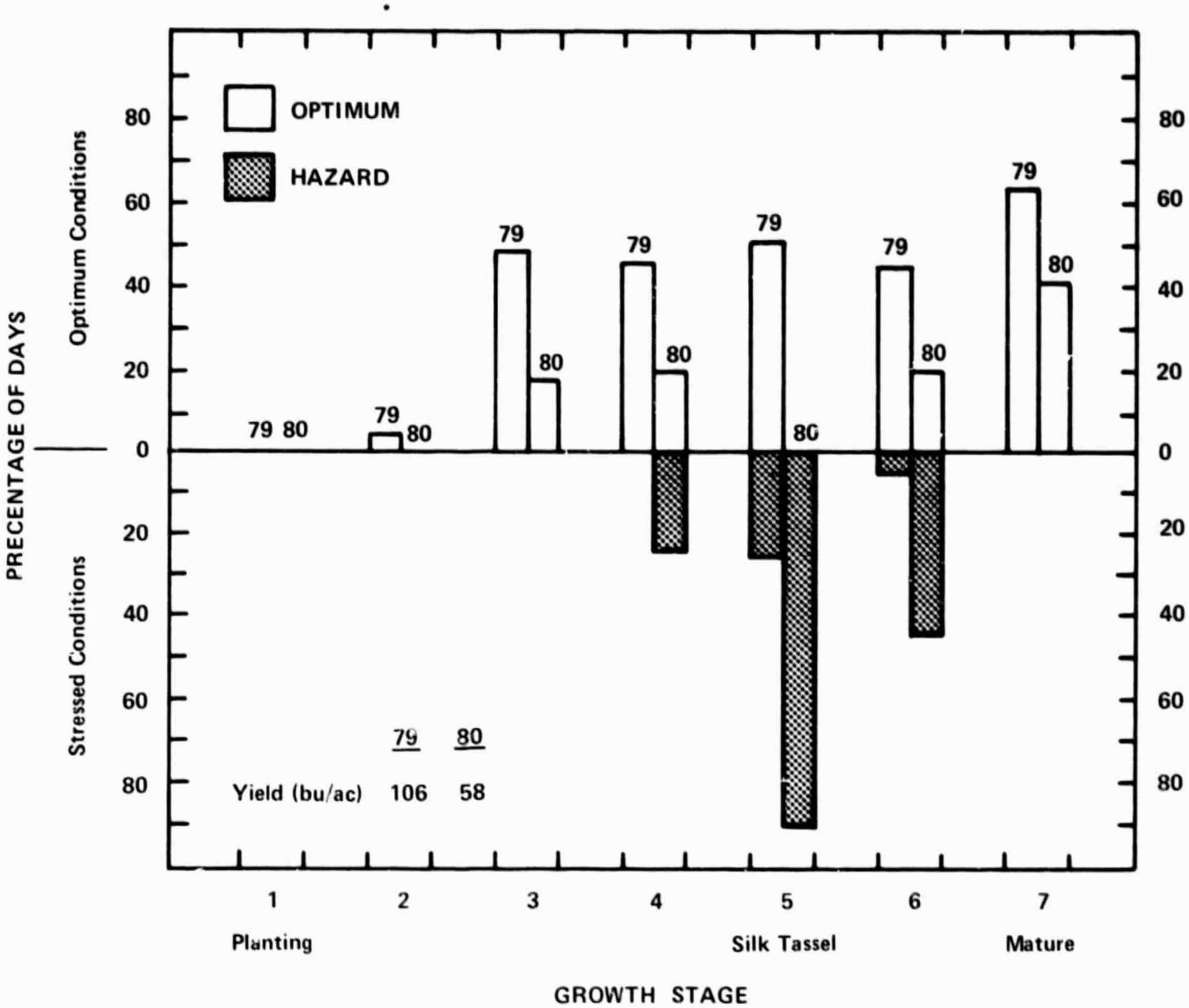


Figure 3.- Comparison of corn stress model alerts by growth stage for N.W. Missouri Crop Reporting District in 1979-80 crop years. (In 1979, the model identified a minor problem at stage 5. In 1980, a poor crop year, the model provided an alert at stage 4.)

model results and corn yield. Wheat, corn, sorghum, and sugar beet stress models have been transferred to the USDA/FAS for operational applications.

Modeling efforts were also directed toward the prediction of disease epidemics, particularly rusts, of small grains. Major pathogens have been identified along with inoculum sources for all major agricultural areas of the world. Meteorological conditions are of paramount importance in disease spread and progression. The meteorological conditions of importance during different critical phases have been defined for several pathogens, with major emphasis on stripe rust. Initial spectral data analysis indicates the feasibility of making a disease impact assessment based on such a meteorologically driven model.

4.1.3 Condition Assessment

A significant contribution in FY 1982 was the development of the crop water stress index (CWSI). This index, based on

the difference between plant canopy and ambient air temperature and vapor pressure deficit, appears to predict drought stress for cotton, wheat, and alfalfa.

Studies were made to determine if monitoring rangelands could be used to assess drought stress in adjacent croplands (fig. 4). Initial findings suggest a potential for using rangeland as a soil moisture/crop stress indicator. This was done by computing vegetative index numbers (VIN's) for rangeland adjacent to cropland. The largest VIN's computed for rangeland vegetation during the maximum green phase for spring wheat and/or corn coincide with years of maximum yield for both wheat and corn. This rangeland study used 4 years of data and indicates that Landsat acquisitions are too infrequent to provide prestress indicator information for adjacent cropland. However, future research may demonstrate the utility of meteorological satellite data for this purpose.

Hot, dry winds, such as the sukovey in the U.S.S.R., can cause a significant decrease in yield of spring and winter wheat. A yield reduction model incorporating potential evapotranspiration, temperature, and available soil water was developed and is being tested for the U.S.S.R. and U.S. Great Plains. Initial results are encouraging.

The EW/CCA project is utilizing an established geographical grid with a United States data base for evaluating satellite-derived information. Each grid cell represents an area of approximately 25 by 25 miles. The data base contains

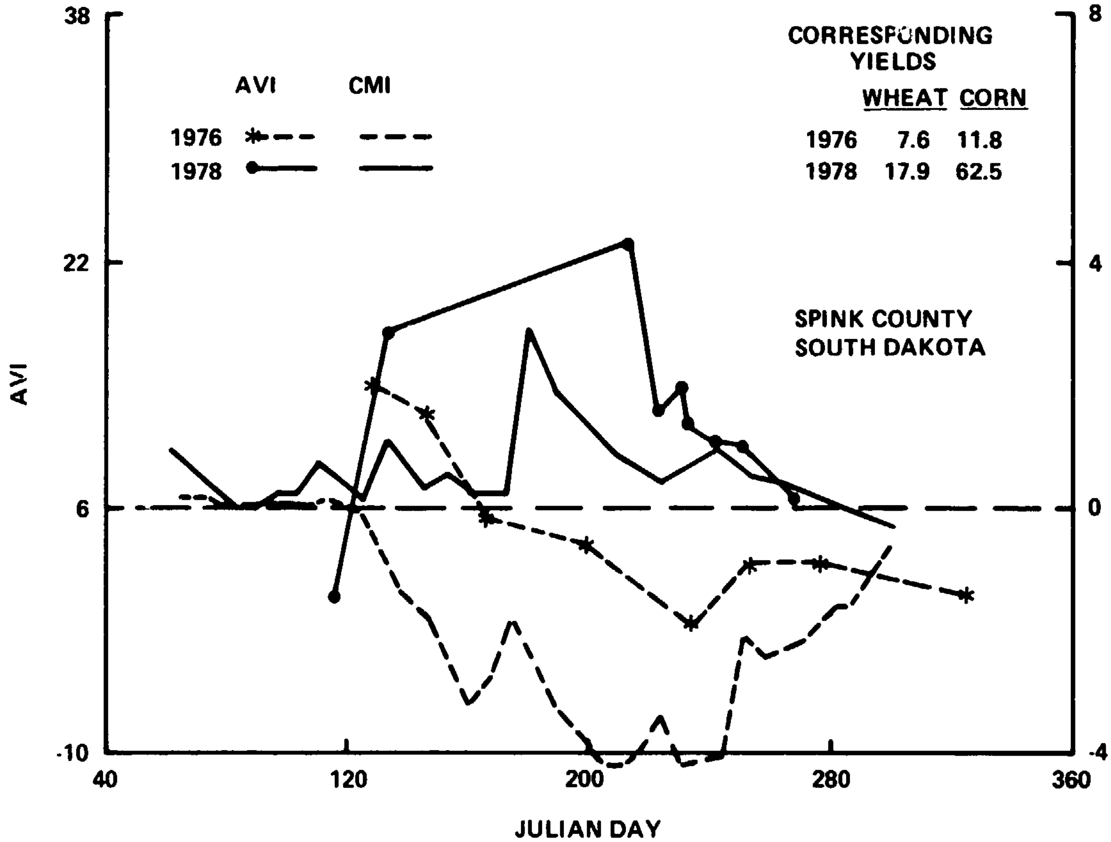


Figure 4.- Ashburn Vegetative Index (AVI) and Crop Moisture Index (CMI) for rangeland vegetation. (For 1976, a low-yield year, both AVI and CMI were low; for 1978, a good yield year, both were high.)

geographic and physiographic data for each cell including: political entities, land resource areas, major soil types, and major crops with associated crop calendars. Each cell is referenced to meteorological data. The meteorological data include: daily precipitation, maximum and minimum temperatures, evapotranspiration, snow cover, and solar radiation.

The satellite data are used to compute VIN's for each grid cell which indicates changes in scene greenness throughout the growing season. These data indicate that satellite-derived vegetative index values provide useful crop condition information for large-area analysis.

4.1.4 Environmental Satellites

The application of environmental satellite data [NOAA-6, NOAA-7, and Geostationary Operational Environmental Satellite (GOES)] was studied as an agricultural surveillance tool. For large-area estimates, vegetative indices, based on data from these satellites, can be used to bridge the spatial and temporal gaps in Landsat data because the environmental satellite data are available daily.

During the past year, NOAA has provided a weekly, worldwide depiction of a vegetative index based on the technology developed in EW/CCA. These products have proven very useful, and it is clear that the most efficient procedures for EW/CCA will be based on a mixture of environmental and Landsat data.

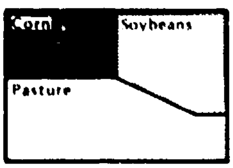
4.2 INVENTORY TECHNOLOGY DEVELOPMENT

The objective of the ITD project activity is to develop and test techniques for using space remote sensing technology to provide objective, timely, and reliable forecasts of foreign crop production without requiring ground observations. The prospective users of this technology are the USDA/FAS and various international organizations concerned with world food and fiber supply. The ITD project is managed by NASA with participation by USDA and NOAA.

In achieving its objective, the ITD project focuses research on important growing regions in the United States and foreign countries. The crops being studied are small grains, corn, and soybeans. The ITD research expands and improves upon the remote sensing technology developed in previous experiments during the mid-1970's.

INVENTORY TECHNOLOGY DEVELOPMENT

The ITD project is researching techniques to monitor major commodities (wheat, barley, corn, and soybeans) in five foreign countries and in five similar growing areas in the United States.



For example, interpreting techniques for images of Brazilian crops may be aided by comparing them to images of crops grown in the State of Georgia.

4.2.1 Technical Objectives

The FY 1982 technical objectives were focused on the following:

- Initial research investigations for quality and utility of the data from the new Landsat TM.

- Research and development of new approaches for early-season area estimation, estimation of area change, and area estimation not requiring precise multitemporal registration or rectification of data.

- Continued development of summer crop, corn, and soybeans inventory technology to make it more efficient and to improve accuracy; developing further understanding of the sensitivities of small grains and summer crops inventory technology to the cultural, environmental, and satellite overpass frequency factors; extending these automated technologies to include winter grains; and further research of these technologies for application in the U.S.S.R., Australia, and Argentina.

- Investigating the utility of multisensor data for agricultural applications (e.g., spaceborne radars and NOAA environmental satellites used in conjunction with Landsat).

- Completing the development of a simulation capability for quantifying the performance of large-area crop inventory technology and for analyzing the sensitivities of selected parameters.

4.2.2 Landsat TM Data Quality and Agricultural Investigations

The ITD, in conjunction with the Goddard Space Flight Center (GSFC) Landsat TM Image Quality Technology Assessment Program, conducted a 'quick-look' analysis of the initial Landsat TM data scene which was acquired over Detroit, Michigan, on July 20, 1982. Preparatory research was conducted during FY 1982 with TMS data acquired by a NASA airborne scanner. The initial TM scene contained only the first four bands of the total seven bands. A variety of studies was conducted to assess varying aspects of the TM data, using segments extracted

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from the full scene, a portion of which is shown on the cover of this report. The following paragraphs describe the more significant early results.

Spatial Resolution

By selecting man-made features of known dimensions (e.g., highways, airfields, buildings, and isolated water bodies), an assessment was made of the TM performance relative to the specified 30-meter (98-foot) resolution. Indications are that this resolution was achieved or exceeded.

In the MSS data, a significant percentage of pixels contain more than one crop of interest, and this has been responsible for a major portion of the error in crop area estimates. TM data over agricultural areas exhibited a very small portion of boundary pixels - a 3 to 1 improvement over MSS data. Thus, the improved TM spatial resolution should result in a significant improvement in the accuracy of crop inventory.

Signal-to-Noise (S/N) Ratio

An important feature of the TM is an improved instrument sensitivity described as a high S/N ratio. Data over different water bodies (a "homogeneous" target) were studied, and the TM appears to be performing better than the advertised specifications.

Spectral Analysis

Studies of the spectral content of the TM data led to conclusions similar to those discovered in TMS analyses. Research analysis revealed a strong correlation between the TM spectral values and the expected values for the particular target crop classes. The response in band 1 contradicted early speculation that this band would be of little value because of the interference of haze and other atmospheric effects.

Spectral Separability

To assess the potentially improved separability of agricultural features with TM, a computer clustering routine was applied to several coincident TM/MSS data sets; figure 5 shows a typical result. The increased spatial and spectral resolution is evident.

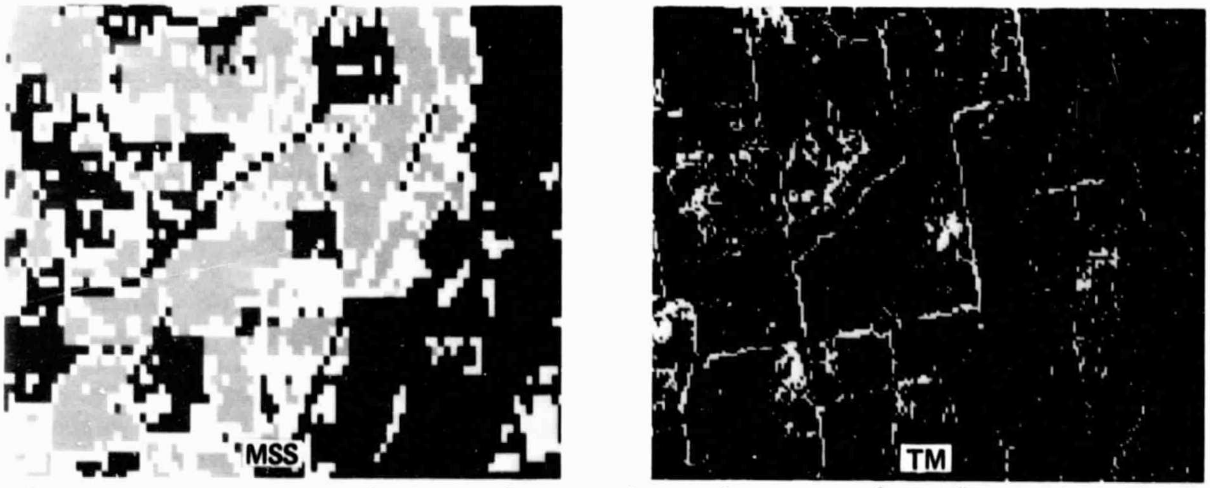

Figure 5.- Comparison of clustering results using MSS and TM data. (Application of a clustering routine resulted in 13 spectral categories for TM versus 4 for the MSS.)

Techniques developed to discriminate color differences were applied to several of the segments containing large water surface areas. The differences in water color, which relate to boundaries due to turbidity, were clearly distinguished. This result was not achievable with MSS and is probably due to the inclusion of the 'blue' band (0.45-0.52 m), the narrower bandwidths, the increased S/N ratio, and increased quantization of the TM.

In earlier TMS studies, the potential improvements in crop spectral separability were evaluated with an approach using the TMS bands 2, 3, and 4 (as 'equivalent' to the MSS bands 4, 5, 7) and, sequentially, adding the TMS bands 1, 5, 6, and 7. An assessment of the potential contribution of these new bands was obtained with the following observations:

- The addition of band 1 (0.45-0.52 m) increases the discrimination of corn from soybeans; some late maturing corn fields, previously confused with soybeans, were identified as a separate corn class (fig. 6).
- TM band 5 (1.55-1.75 m) also identified the late corn fields and appeared to react to the vigor of the vegetation. This reaction was probably related to overall water content and/or soil moisture.
- TM band 7 (2.08-2.35 m) and band 6 (10.4-12.5 m), acquired in late August, did not seem to improve the overall crop discrimination. However, several patterns were noted that were probably related to the difference in vegetative condition and/or features beneath the vegetative canopy.

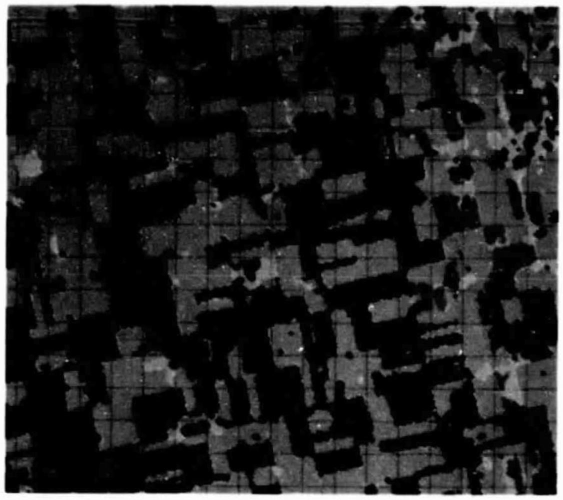

Figure 6.- Classification of five categories based on TMS bands 1, 2, 3, and 4 data acquired on August 30, 1979, from Webster County, Iowa. (Crop codes: brown-corn, orange-late corn, green and yellow-soybeans, and blue-other land cover.)

Crop Proportion Estimation

From a TMS analysis of crop proportion estimation performance, each band's contributions are recognized. Figure 7 illustrates the significance of each band. Note that these proportion estimates were accomplished with a single acquisition.

Principal Components Analysis

Four potentially useful components for crop separability were obtained from the four TM spectral bands. The first two principal components appear to be highly analogous to the MSS greenness and brightness components, leading to the expectation that the second two components will contain other useful information.

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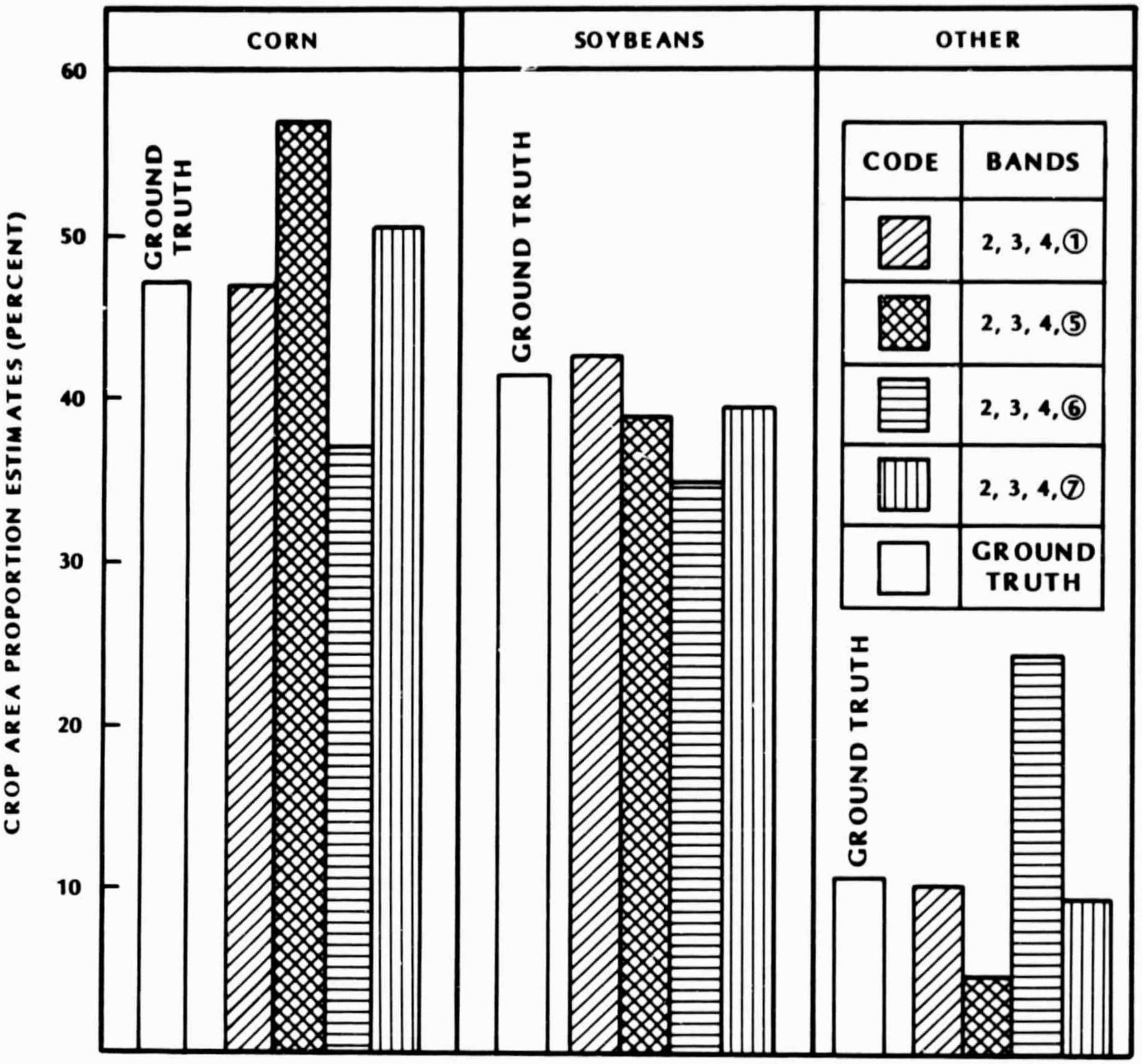

Figure 7.- Corn/soybeans/other detection test results using each of TM bands 1, 5, 6, and 7 together with the equivalent MSS bands 2, 3, and 4. (Adding band 1 or 7 gave better results than 5 or 6. Ground truth is the percentage of each crop in the test segment.)

4.2.3 Early-Season Estimation of Crop Areas - Spring Small Grains

Previous spring small grains area estimation techniques had been shown to be highly efficient and of reasonable accuracy, but were only applicable to the latter part of the growing season.

During FY 1982, a technique was developed and tested that indicates (a) estimates of crop areas can be made early in the season, when the information is much more valuable and (b) further reduction in the cost of data analysis can be accomplished. This early-season method relates growing degree days (a

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measure of the accumulated energy available to the plant for growth) and the response of a Landsat sample segment in terms of a weighted summation of the responses of the ground cover classes in the segment. Figure 8 shows the spectral response values as a function of time for selected cover classes. Note that the curve for spring small grains is highly distinct from other classes in the 200-600 growing-degree-day period. The technique was tested using data for 100 segments in four U.S. states and one Canadian province; the data were distributed across crop years 1976, 1977, 1978, and 1979.

This early-season method achieved accurate results prior to the crop stage of tillering. The results are highly correlated ($r2 = 0.78$), with ground observations having a relative mean error of 3.28 percent and a standard deviation of 7.47 percent. These results are comparable in accuracy to previous end-of-season results. Because the method operates at the segment level, data storage costs, analysis computation costs, and savings in satellite data costs are possible.

This technique has been transferred to the USDA/FAS Foreign Crop Condition Assessment Division and installed on their computer for operational evaluation and use.

4.2.4 Aggregation of Sample Crop Area Estimates to Large-Area Estimates

Accurate large-area (e.g., state-level) crop acreage estimates obtained by aggregating sample segment estimates were improved. In this effort, two improvements to previous aggregation approaches were tested, using both Landsat-derived segment crop area estimates and segment crop area measurements obtained by USDA ground visits. Both approaches demonstrated the ability to produce a more precise estimate from a given set of segment estimates than that produced with previous approaches. One approach is a fully automated computer procedure that eliminates the need for analyst intervention by producing mathematically optimal stratum and region estimates from the available data. The technique resulted in a 12-percent reduction in

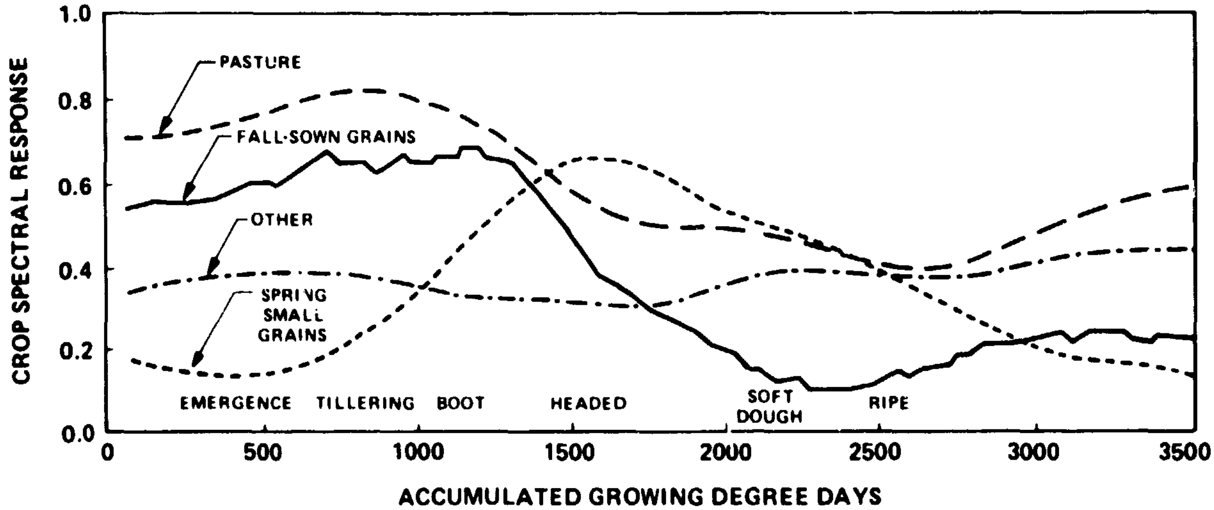


Figure 8.- Vegetative responses of crop groups. (Spring small grains exhibit a distinctive response in the early season.)

variance in a test over North Dakota. The other approach, an improved procedure, employs Landsat-derived segment crop proportion estimates from multiple years to produce stratum area estimates. By taking advantage of the correlation between segment crop proportion estimates from year to year, the procedure contributed an additional 25-percent variance reduction in the North Dakota test.

4.2.5 Sampling and Aggregation for Large-Area Change Estimation

During the past year, ITD has evaluated the concept of employing year-to-year crop area change estimation as a means of reducing the total number of sample segments required for large-area crop estimation. Crop area change in a segment is highly correlated between years, and the difference in crop area from one segment to another may be large. A study of this effect was conducted with data from spring-wheat-growing regions of the U.S.S.R. for the 1976 and 1977 crop years. The results indicate that a change estimation approach to large area crop estimation allows a reduction, by approximately 25 percent, of the total number of segments for the aggregation system by taking advantage of the year-to-year "correlation."

4.2.6 Development of a Simulation Capability for Quantifying Performance of Large-Area Crop Inventory Technologies

During FY 1982, ITD developed a set of generalized design and evaluation tools that allow the objective comparison of alternative spectral transforms, data preprocessing options, and crop calendars.

Vegetative spectral responses of major crop groups and the degree to which confusion between crop groups is likely at any particular time can now be estimated. Based on these responses, the probability of correct classification can be calculated for a specified crop and each potential confusion category. Figure 9 shows a plot of separability using spring small grains as the specified crop.

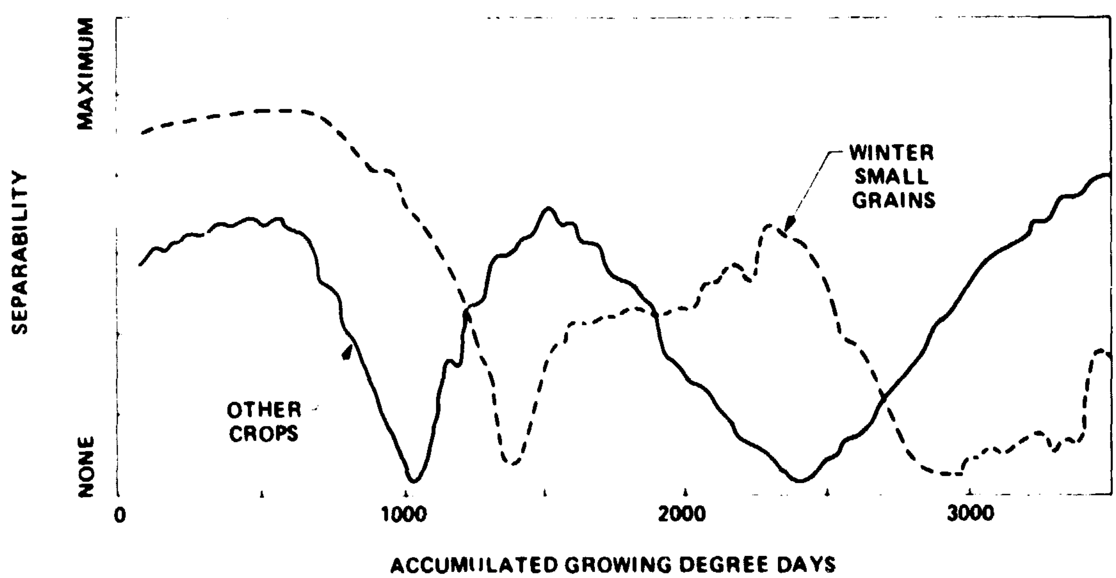


Figure 9.- Separability of spring small grains from confusion crops. (The horizontal axis represents spring small grains; therefore, the curves of confusion crops represent the degree of separability from spring small grains.)

4.2.7 Investigations of Satellite Radar Utility

Two investigations were undertaken to evaluate the utility of satellite SAR data for use in agricultural inventories. Such radar systems are attractive for use in agricultural surveys by virtue of their all-weather, day-night, and high-resolution capabilities that would permit acquisition of data at the most agriculturally opportune times and with a great deal of spatial information. Such radar data could complement Landsat visible and infrared data.

The specific objective of the first study was to assess the value of augmenting the Landsat MSS with Seasat SAR data in the context of agricultural inventories. Data acquired on July 25, 1978, for a site in Jasper County, Indiana were analyzed. The results of the investigation revealed that the finer spatial resolution of the Seasat (25 m versus 78 m for the Landsat MSS) can provide a better definition of field boundaries and that features called tone and texture can be used to improve specific crop labeling accuracies in Landsat images. In addition, it was found that the Seasat radar data of July 25 provided an ability to discriminate corn from soybeans, whereas, the corresponding information from Landsat MSS data was apparent only later in the season.

A second investigation, initiated to evaluate the agricultural information content of satellite radar data, was focused on data acquired over an agricultural area of New South Wales, Australia, by the Shuttle Imaging Radar-A (SIR-A) during the second mission of the Space Shuttle on November 14, 1981. Crop photoanalysis techniques were applied to the SIR-A image product and corresponding images of Landsat data acquired on several dates during 1977 and 1979. Numerous landform and cultural features are discernible on the radar image (fig. 10). Mountains, rivers, forests, roads, and agricultural areas are readily apparent. Field boundaries can be seen corresponding to roads and fences (with associated fence-line vegetation) surrounding most fields. Several tones or shades of gray are detectable in the agricultural fields related to type, density, and condition of the vegetation. In this area of Australia, the agriculture is concentrated on wheat and sheep production; hence, most of the agricultural fields are wheat, pasture, or fallow.

Based on this preliminary examination, it appears that SIR-A type data could prove useful in the development of more efficient sampling strategies through sample frame development, stratification, and precise sample unit location. It may be useful as a base for collection of ground observations if adequate photography is unavailable. SIR-A type data may also have utility in crop identification for inventory purposes or in crop condition assessment, particularly in cases where data collection, close to a deleterious weather event such as hail or flood, is advantageous.

4.2.8 Argentina Sample Frame Development

A sample frame was created for selected geographic areas in Argentina to support the development and testing of area estimation methodology. The sample frame was developed for three provinces, Buenos Aires, Cordoba, and Santa Fe, and was constructed to provide for increased sampling efficiency for corn, soybeans, and wheat.

The target region was divided into homogeneous areas based on Landsat imagery, field patterns, and soil type. Digitized homogeneous polygons were "registered" to a segment grid. The following characteristics of each segment were recorded based on the location of the center point

Figure 10.- SIR-A image of New South Wales, Australia, acquired November 14, 1981. [This image covers a 50-by-100 km (31-by-62 mi) area and shows features as small as 60 m (200 ft). The area is primarily cropland featuring small grains and pastures.]

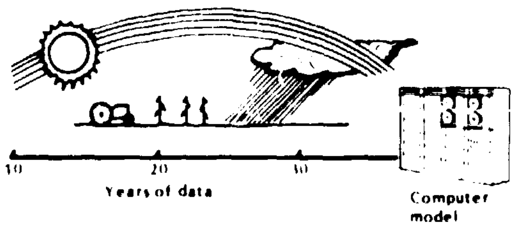
of the segment: percentage of cultivated area; percentage of the area devoted to corn or soybeans; percentage of the area devoted to wheat; and field size, political subdivisions, and soil type. Both segment and polygon information are stored for statistical analysis.

4.3 YIELD MODEL DEVELOPMENT

The YMD research effort utilizes the measurement of environmental and plant characteristics to project crop yield potential within a region. This effort is a key component of any commodity production forecasting methodology and, as such, contributes to both the domestic and foreign crop estimation processes. NOAA, through the Environmental Data and Information Service, Center for Environmental Assessment Services (EDIS/CEAS), manages this activity with support from USDA and NASA.

YIELD MODEL DEVELOPMENT

This is research to determine how various crops will respond to weather conditions, agricultural practices, and other factors. Many years of data are taken into account.



4.3.1 Technical Objectives

The FY 1982 objectives for this activity were:

- To test and evaluate candidate crop yield models.
- To perform research to develop new and improved crop yield models.
- To acquire, process, and store meteorological and satellite data.

4.3.2 Yield Model Test and Evaluation

The initial phase involved the application of test criteria for evaluating statistical crop yield models. These tests were applied to the CEAS, Thompson-type, and Williams-type regression models for soybeans, corn, wheat, and barley. The Williams-type and CEAS spring wheat and barley models were compared. These models differ in their input variables, but are very simillar in other respects. The conclusion is that the CEAS model is only slightly preferable for AgRISTARS applications, and the Williams-type model should not be eliminated from further consideration.

The second phase of this task was to test selected plant simulation models which attempt to describe the physical and biological processes in plant growth and development. Daily meteorological data were used. This phase followed a review of higher order models.

The first simulation model tested was the Texas A&M University wheat model (TAM W) applied to spring wheat in North Dakota. Preliminary results indicate the yield output is very sensitive to the soil moisture budget, and phenological accuracy is critical. The results appear promising. Modifications and tuning of the model seem necessary for application to other areas.

The CERES-wheat model, developed by the USDA/ARS group at Temple, Texas, is also a candidate for testing. Data have been acquired to test this model in areas other than the United States. Two recent modifications of the model have probably made it more sensitive to (a) the dry conditions found in the U.S. Great Plains region and (b) the phenological development pattern of spring wheat.

The CERES-maize model, also developed by the group at Temple, Texas, has been acquired for further testing. The CERES-maize model presents a new algorithm for simulating the separate effects of day length and temperature; the model should be able to predict performance of a hybrid planted in any region at any time.

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4.3.3 Yield Model Research and Development

Simulation models to estimate plant progress are being developed. As a first step, a phenology submodel was developed. A flexible and highly modular computer program was completed. Coefficients expressing the effects of day length and temperature on development are nearly ready for testing. USDA/ARS personnel in Illinois and Mississippi are collecting controlled environment and field data to support further simulation model development for cotton, soybeans, wheat, corn, and sorghum.

Vegetation indices derived from Landsat-1 and Landsat-2 observations of crop fields have been related to the plant parameters, leaf area index (LAI), population, and yield of grain sorghum. The vegetation indices appear to capture the 'greenness' or photosynthetic potential of the entire canopies. As such, they have been proposed as spectral surrogates of LAI in the light-interception subroutines of crop growth and yield simulation models. In addition, a soil line index has been devised which, when plotted against the vegetation index, appears to indicate when the plant canopy is sufficiently developed such that available sunlight is essentially fully utilized by the crop canopy. These findings require testing, but they provide the possibility of providing information for the photosynthesis/dry matter accumulation subroutines of crop growth and yield simulation models for any field of interest in the United States or abroad.

Statistical models have been developed for selected parts of the world. These include: Argentine wheat, Australian wheat, Eastern European wheat, and U.S.S.R. barley. The 'bootstrap test' results suggest some bias in the models. However, these are considered first approximation models to be used only as initial tools. The more complicated physiological models must be validated for applications to other parts of the globe prior to operational use.

Examination of Landsat data for wheat in the U.S. Central Plains has provided strong evidence of a broad area relationship between the spectral properties and end-of-season yield of a crop. For winter wheat in 1978 and spring wheat in 1979, linear relationships were found between segment-average 'greenness' at heading and Crop Reporting District (CRD) or county-level reported yield (fig. 11). The slopes for the two cases were virtually identical. Application of the winter wheat relationship to spectral data from the NOAA-6 AVHRR sensor averaged over CRD's in Texas, Oklahoma, and Kansas, gave predicted yields very close to the reported yields.

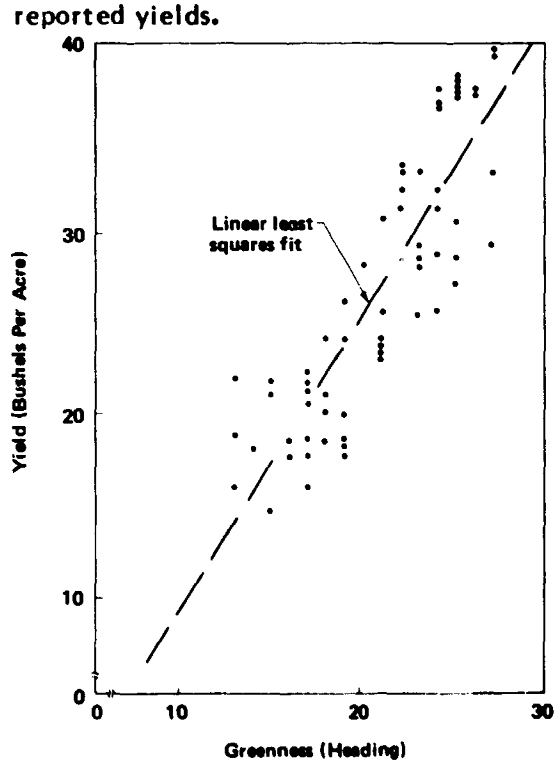


Figure 11.- Spring wheat county yields versus segment average greenness at heading for 1979. (Data are from North and South Dakota, Montana, and Minnesota.)

Model testing also involved the aggregation of small, but homogeneous, areas into relatively larger areas called agrophysical units (APU's) to determine whether a more accurate estimate of yield can be achieved by using homogeneous areas having similar soil types, climate, and cropping practices. When the results of these models were aggregated to the state level and compared with the CRD levels, also aggregated to the state level, it was found that the results were similar; i.e., the APU models were not better than the CRD models. One preliminary conclusion derived from this study showed the standard error of the yield, estimated from the aggregation of CRD models to a state level, was smaller than that of an estimate derived from a single state model. This suggests that, for practical application, a CRD level is desirable. This conclusion is also supported by the analysis of the variability of the greenness index at pixel-, field-, segment-, and CRD-size data levels.

4.3.4 Data Acquisition Processing and Storage

To provide data to test the complex crop models, daily historical data (maximum and minimum temperatures and precipitation) were processed for various areas including the United States, U.S.S.R., Argentina, Brazil, Canada, China, India, and Australia. Monthly temperature and precipitation historical series have also been developed for application to simple statistical modeling and development of indices to stratify similar areas.

Several clustering techniques were compared to stratify areas into similar regions for the purpose of applying crop yield models to areas other than where the model was developed. The similarity areas were identified based on selected temperature and precipitation data (fig. 12). With additional spatial and temporal data, it may be possible to arrive at unique areas with this technique.

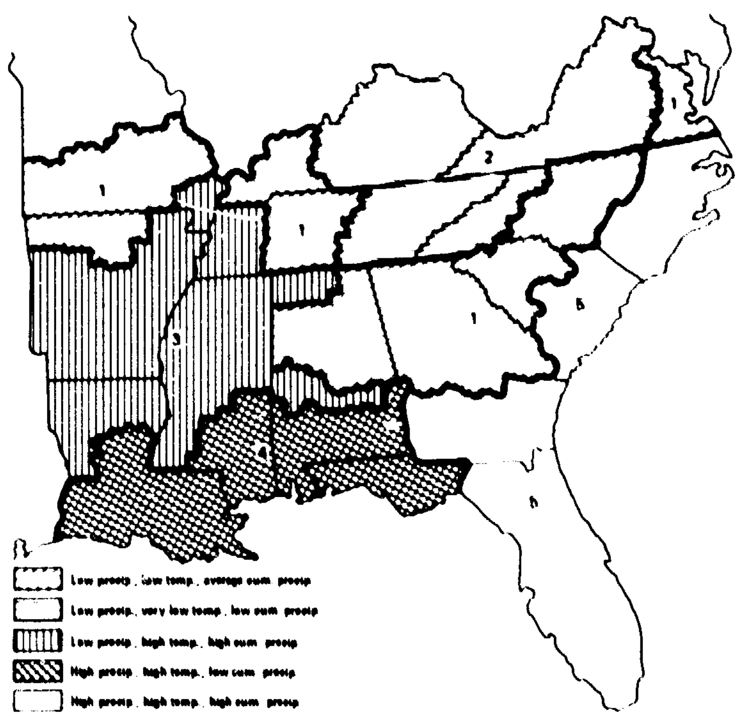


Figure 12.- Climatic clustering of areas in southeastern United States.

Maximum and minimum temperatures are important inputs to crop yield and phenological models. Two methods that provided estimates of the high and low temperatures for a day were compared. In the first method, when the maximum and minimum temperature were not specifically reported, a parabolic equation was used to estimate the value from a three-hour synoptic report. In the second method, the highest and lowest reported values for the day were assumed to be the maximum and minimum temperatures. It was concluded that the difference between the two methods was minor. Therefore, from a practical viewpoint, the highest and lowest value method sufficed for estimates of the maximum and minimum temperature for the day.

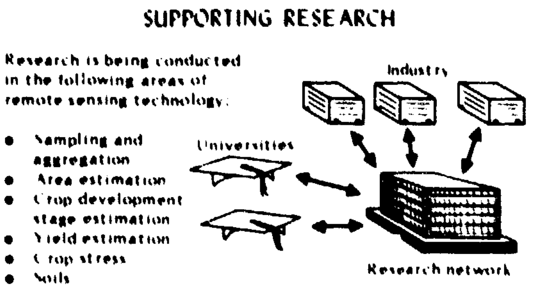
An experimental, satellite-derived, solar radiation data base provided by NOAA National Environmental Satellite Service (NESS) was compared with the ground-observed network at 15 locations in the United States for the period July 1980 through October 1981. The results were generally very good except for the coastal areas. These satellite data will be used in testing crop models requiring this variable.

A unique data set comprised of synchronous GOES-E infrared data and surface reports of rainfall from the NOAA Service-A network over the U.S. midwestern states has been archived using the Man-Computer Interactive Data Access System at the University of Wisconsin at Madison. The data consist of nearly 22,000 cases collected from June and July of 1981 and August 1979. Statistical analysis was used to determine the threshold brightness value to discriminate between rain and no-rain events. Evaluation of this technique shows that, while the predictive skill varies somewhat with region and time of year, some 60 percent of the rain/no-rain events can be correctly classified.

4.4 SUPPORTING RESEARCH

This project is designed to provide technological components and procedures for testing in the other AgRISTARS projects, notably in the crop inventory activities. Research focuses on techniques to extract, from Landsat data, information on the area planted to different crops; on the stage of development of wheat, barley, corn, and soybeans; and on the crop condition determined from spectral analyses of the crops. The SR project is managed by NASA with support from USDA and NOAA.

The crops of concern to the EW/CCA and ITD projects are being studied by the SR project. In addition, natural vegetation and soils are important subjects of study.



4.4.1 Technical Objectives

The focus of work in FY 1982 was on the following:

- Research and development of automated extraction of crop area information from Landsat multispectral data.
- Research and development of techniques to estimate crop stage and condition.
- Improvement of the technology for registration and research analysis of multitemporal Landsat images.
- Landsat TM data evaluation.
- Research into the use of radar data for crop identification.

4.4.2 Automated Extraction of Crop Area Information

During FY 1982, major advances in the technology were accomplished. A highly automated technique was developed and successfully tested for classifying corn and soybean crop areas near harvest. For the more difficult task of identifying small grains, development of crop temporal profiles has led to encouraging test results.

Corn/Soybeans

Underlying the success of the highly automated technology was the development of a crop temporal profile technique which permits multidate Landsat spectral data to be interpreted in terms of key vegetation growth parameters. The resultant parameters, such as date of emergence, peak greenness, length of growing season, and maturity stage, can be uniquely related to specific crop types.

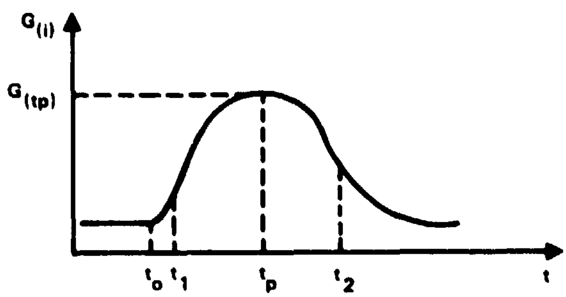


Figure 13.- A typical crop greenness temporal profile. (Greenness is the y-axis; time is the x-axis; t_0 is the start at crop green-up; t_1 and t_2 are the inflection points; and t_p is peak greenness.)

A typical crop temporal profile is shown in figure 13. The greenness G is

computed from Landsat spectral data. The variables used are the time of peak greenness, tp; the value of the peak greenness, G(tp) and $\sigma = t_2 - t_1$, where t_1 and t_2 are the left and right inflection points of the fitted profile. The relationship between these parameters and crop types has been demonstrated to be unique within the United States for corn and soybeans and to be stable over years and regions.

This corn/soybeans technique is highly automated in the sense that once the computer is initially trained on crop data from a few sample segments, no further human interaction is required. Figure 14 shows a flow diagram of this technique. It was successfully tested over all key growing regions in the U.S. Corn Belt and the Mississippi Delta for 3 crop years. Figure 15 illustrates the results of this testing in which 56 segments showed no significant bias and had a relative mean error of 3 percent and a relative standard deviation of 8.2 percent. This represents a higher accuracy for crop identification and proportion estimation than previously obtained, specially for those techniques requiring time-consuming manual inputs. This accomplishment places the technology on the verge of maturity; only testing in a foreign corn/soybeans region remains.

Small Grains

Small grains identification and proportion estimation represent a more complex problem and cannot be solved with the corn/soybeans approach. For this reason, significant research has been conducted for the Advanced Proportion Estimation Procedure (APEP); see the FY 1981 AgRISTARS Annual Report. The APEP has the advantage that it uses all available information affecting crop growth. The crop temporal profiles are derived from Landsat spectral data, and variables derived from these profiles are used to determine crop distributions from a "mixture model." Figure 16 shows a typical distribution of crop signatures within a Landsat small grains sample segment and the statistical mixture model distributions derived to match the observed distributions. The distributions are identified as crops using agrometeorological crop development models.

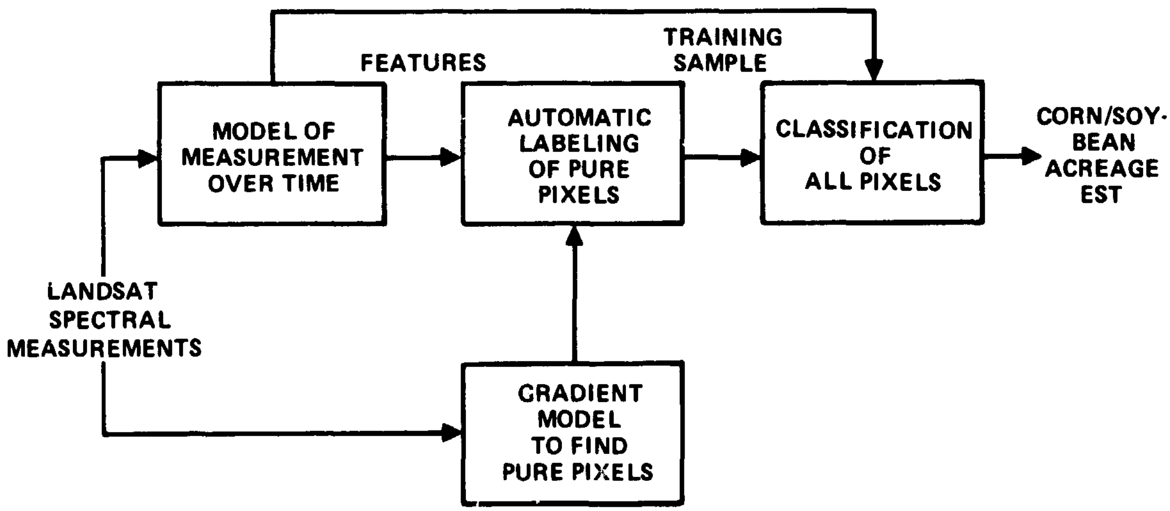


Figure 14.- Corn/soybeans highly automated technique.

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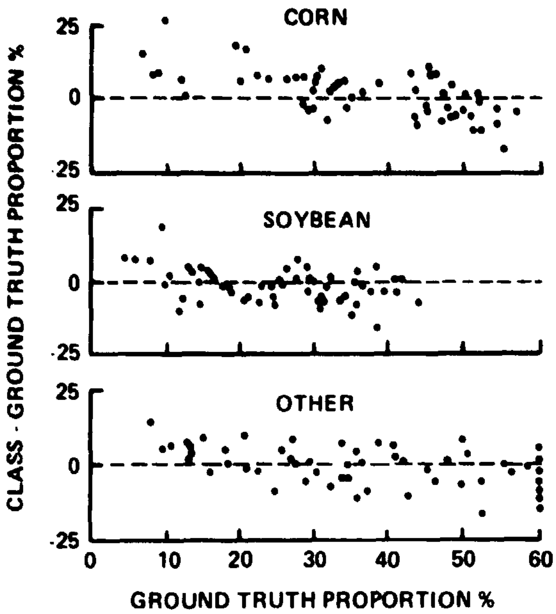

Figure 15.- Corn/soybeans technique classification results. (Ordinate is classification results minus ground truth in percentage versus percentages of crops in segments for corn, soybeans, and other crops.)

Initial testing of the procedure for 18 segments in the U. S. Northern Great Plains has yielded two conclusions: first, crop mixture distributions can be reliably associated with either small grains or non-small grains; second, accurate small grains proportion estimates can be obtained by summing the proportion of each small grains component. In addition, encouraging accuracy was obtained; a relative mean error at 3.7 percent and a relative standard deviation of 12.7 percent were obtained for the 18 segments.

The automatic labeling of crop distribution functions is a goal for APEP research. Studies to date show a correspondence between crop temporal profiles and weather-driven crop development models. Although further work remains, results to date are encouraging.

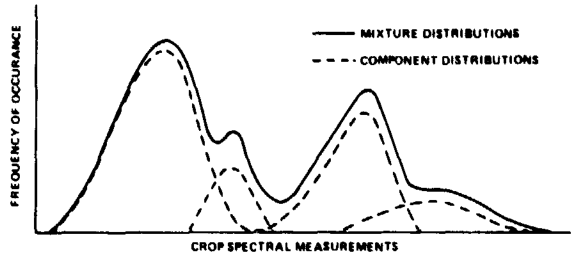

Figure 16.- Typical distribution of crop signatures and the statistical mixture models' distrubutions derived.

Mathematics - Statistics Research

Questions have arisen on the assumption of statistical normality for the component distribution functions for crops in the mixture models of the APEP. In some cases, symmetrical functions, which are non-normally spread, fit the data better, whereas, in other cases asymmetrical non-normal functions fit better. Special distribution functions to fit the non-normal cases have been tried, and initial improvements in APEP results are encouraging.

4.4.3 Crop Stage and Condition Estimation

Another major area of research in the SR project is the estimation of crop stage and condition. Again, Crop Temporal Profile technology has made possible a major breakthrough to a long-standing problem - the accurate estimation of crop emergence date - critically needed to start the agricultural-meteorological (agromet) stage of maturity models. Research results to date indicate that the Crop Temporal Profile models potentially can be used to estimate accurately other key development stages, such as floral initiation, heading, and senescence. A model which

utilizes a direct relationship between remotely sensed spectral data and soybean development was developed and tested during the year. Several important results were achieved in FY 1982 in the use of spectral data to assess crop condition. They included the spectral estimates of intercepted solar radiation by corn and soybeans and the spectral estimation of LAI as an input to a wheat yield model.

4.4.4 Preprocessing - Registration and Analysis Technology for Landsat Data

The Lyndon B. Johnson Space Center (JSC) registration processor, a technology descendent of the GSFC master data processor (MDP) and the Large Area Crop Inventory Experiment (LACIE) registration processor, has been in operation since November 1981. Initial efforts to adapt the registration processor to accept the new Landsat-4 MSS data as well as the TM data have proven successful. The JSC registration processor will be used to routinely register the MSS and TM data to each other as well as multitemporally register TM data from one date to another in the coming year. Moreover, this unqualified success may indicate that other sensor data, such as Shuttle SIR-A, SIR-B, or Seasat data, can be registered to TM and MSS data in the near future.

An important FY 1982 accomplishment was the development of an integrated system to receive Landsat-4 TM (as well as MSS) data and analyze the data; this sytem provides the capability to image the data and perform many sophisticated pattern recognition and image analysis functions. The data system's effort provides Landsat agromet data vital to research as well as rapid and easy access to these data by providing a comprehensive data base management system. In addition, the data system's support provides an extensive interactive computational environment not only to other AgRISTARS projects within USDA and NASA but also networks these capabilities to the university community which supports AgRISTARS. This data system support permits the user community to have efficient access to a comprehensive set of research data and to share analysis capability.

4.4.5 Landsat TM Data Evaluation

Analysis of the first TM data has shown the performance of the instrument equal to the high expectations. The additional bands in the middle infrared have added significant component to the dimensionality of the data.

Simulations of TM data, using the TMS data, were corroborated when the first TM images were received in late August. These simulations which were provided to ITD, GSFC, and other AgRISTARS agencies enabled adequate data systems and analysis to be in place to support an early evaluation of TM in the agricultural information context (fig. 17). Moreover, this emphasizes the merit of simulation of data from any advanced sensors anticipated in the future.

The increase of spatial resolution of TM (30 m) over MSS (80 m) appears to be significant not only in resolving spectrally distinct classes that were previously undefinable (e.g., roads, small fields) but also in distinguishing within-field variability. This increased spatial resolution, therefore, decreases the effect of the mixed pixels on the boundary and accurately represents variations within a field due to soils, topography, planting, and density.

Tests of the band-to-band registration accuracy of TM data showed that bands 2 to 4 were well within the specification of 0.2 pixels, while bands 2 to 5

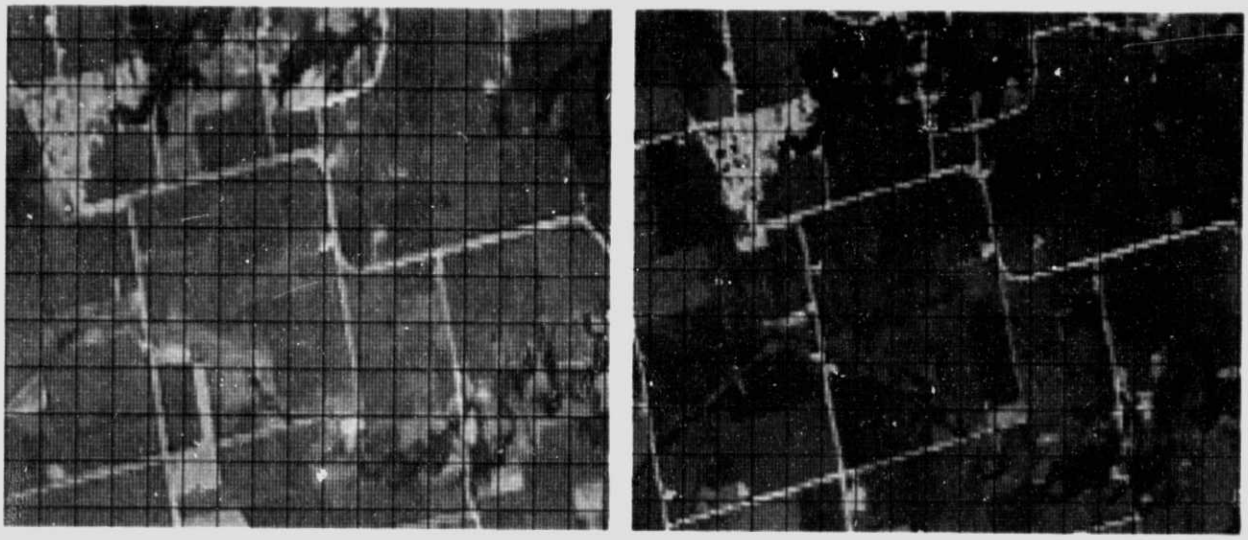

Figure 17.- Actual versus simulated TM data. (Actual TM scene left, simulated scene on right. The area depicted is an agricultural area in Webster County, Iowa.)

were not within an acceptable limit. If not corrected, this misregistration could significantly degrade the ability to utilize multitemporally registered TM data (goal of 0.5 pixels).

Tests of the geometric fidelity of TM were accomplished by choosing points from a U.S. Geological Survey (USGS) quad sheet and allowing the TM data to fit these with freedom of translation and rotation (no "rubber sheeting deformation"). This resultant root mean square error (RMSE) was a successful 1/10 pixel (see fig. 18).

4.4.6 Radar Agriculture Research

<u>Analysis of Colby Radar Data for Crop Identification</u>

An analysis of the usefulness of multidate and multiband radar data, acquired over the Colby, Kansas, test site in the summer of 1978, was completed. An earlier analysis in FY 1981 was made of only the Ku-band radar data, but this effort in FY 1982 included the L-band and C-band radar data, bands of interest to the SIR-B to be flown in August 1984, and to other spacecraft radar imagers in the 1980's. In the test site, four land cover classes were present: irrigated corn, pasture, fallow, and wheat stubble. Corn was most easily identified. For a single date and radar band, the classification accuracy, using field averaged data, was 86 percent to 93 percent for C-band and L-band, respectively. When multidate data were used, the classification of corn was perfect. Pasture, fallow, and wheat stubble, all low vegetation conditions, were not well separated. The results at L-band and C-band were better than those obtained using Ku-band, a relative surprising result.

<u>Analysis of Webster Radar Data for Crop Identification</u>

An analysis of the usefulness of multiband radar data acquired on two dates in 1980 in a corn and soybean test site in Webster County, Iowa, was conducted. The results indicated that

the use of the C-band cross-polarized data (best) or the L-band like-polarized data (second best), taken at a sensor look angle of 50 degrees with HH polarization (Horizontally transmitted, Horizontally received), resulted in excellent separation of corn and soybean fields on the date when the soil was dry (fig. 19). Wet soil background conditions produced poorer separation. Severe row direction effects were noted also for like-polarization, a problem that must be dealt with in future spacecraft missions. It was also found that corn was brighter than soybeans for the L-band data, but it was darker than soybeans for the C-band cross-polarized data. At Ku-band, the two crops had similar backscattering signals, also a surprising result.

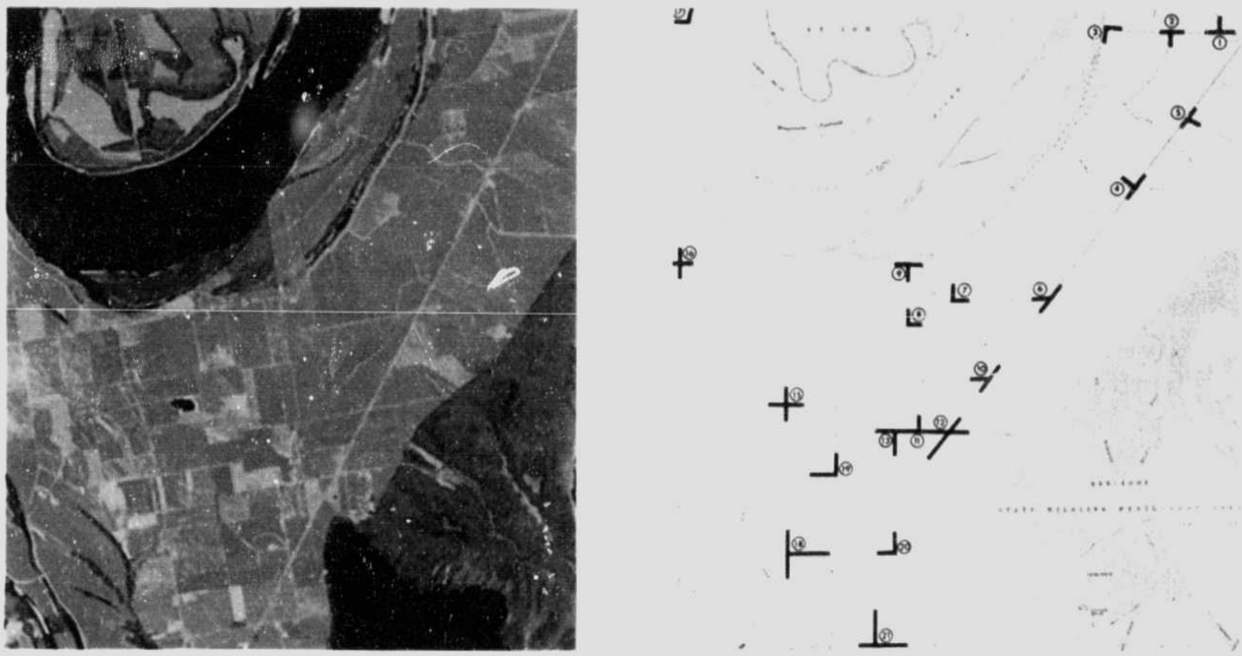

Figure 18.- Illustration of 1/10 pixel accuracy in registration of TM data to USGS quad sheet.

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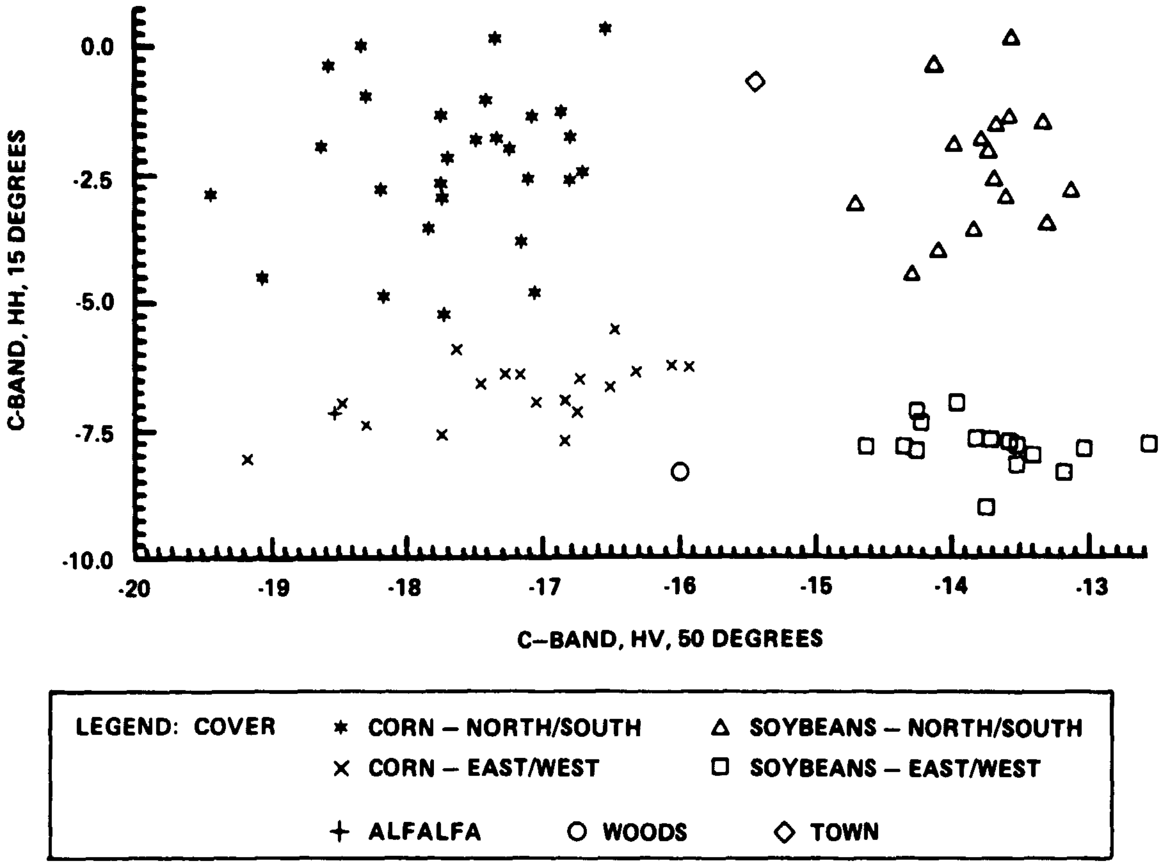


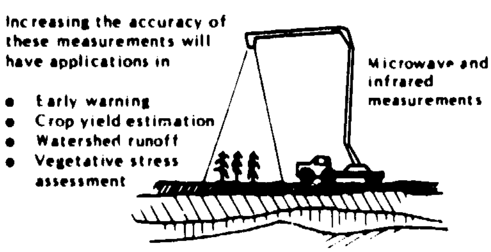
Figure 19.- Separation of crops using two-band scatterplot of C-band radar data. (HH = Horizontally transmitted, Horizontally received; HV = Horizontally transmitted, Vertically received.)

4.5 SOIL MOISTURE

The objective of the SM project is to develop and evaluate the technology for the remote and ground measurements of soil moisture. Development of the technology is an intermediate step in applying the techniques to agricultural information needs. A knowledge of soil moisture is important as input to models for predicting crop yield, plant stress, and watershed runoff. This work will provide knowledge about a key variable needed in several other AgRISTARS projects.

The SM project is managed by the USDA/Soil Conservation Service (SCS), working closely with the USDA/ARS and NASA. The scope of the work includes the improvement of in situ soil moisture measurement techniques; the development and evaluation of remote sensing approaches; and through mathematical modeling efforts, relating the in situ and remote sensing measurements to moisture storage over large areas. Applications of the results will be applied to various agricultural and hydrological problems over broad regions.

SOIL MOISTURE STUDIES



4.5.1 Technical Objectives

Specific FY 1982 technical objectives include the following:

- Continue basic research on microwave sensor development and evaluation, with particular reference to measurement of dielectric properties and the study of roughness and vegetation effects.
- Conduct an assessment of Seasat data utility for soil moisture.
- Complete the development of an in situ soil moisture measurement device.
- Initiate a study of methods for estimating profile moisture content from remotely sensed surface measurements.

4.5.2 Microwave Sensor Development and Evaluation

Soil dielectric constant is the key parameter that links the moisture content of a soil medium to its microwave emission and backscattering properties. Detailed experimental measurements were conducted to determine the dependence of dielectric constant on volumetric moisture content and soil textural composition. The measurements were made to 1.4 and 5 GHz on soils ranging from a sandy loam to a silty clay; an example of the 1.4 GHz results is presented in figure 20. The measured curves were found to be in excellent agreement with a newly developed dielectric mixing model, which incorporates particle-size distribution (texture), salinity, and moisture content. This dielectric constant information is necessary for use in models which predict the microwave sensor response as functions of soil moisture.

An example was presented in the FY 1981 AgRISTARS Annual Report in which the results of a radiative transfer model predicting the 1.4 GHz brightness temperatures for measured soil moisture profiles were compared with the measured values. This analysis has been extended to include the 1980 and 1981 measurements, and again, the results are very good.

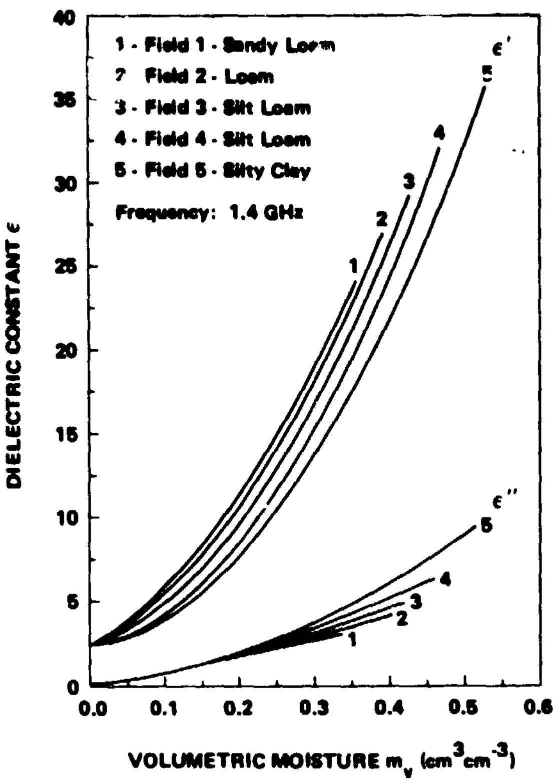


Figure 20.- Measured dielectric constants of five soil types at 1.5 GHz. (ε' is the measured dielectric constant and ε'' is the loss factor caused by soil moisture content. Each curve is the average of 20 data points.)

During field experiments in California, a technique for measuring bare field surface roughness effects on microwave response to soil moisture was used. Poor agreement resulted, and this indicates the need for more advanced models.

Studying the scattering effects in specific plant components, using both active and passive microwave sensors, was attempted during recent experiments. The experiments were conducted by making measurements of an initially undisturbed plant canopy and then repeating the measurements after stripping off the leaves, the fruits, and finally the stalk, at which point a measurement of the bare ground was made. The results for a corn field at 5.1 GHz are given in figure 21. The vegetation cover appears to have negligible effect on the radar return when the view angle is within 15 degrees of vertical. Here the observed return is dominated by the backscatter from the soil, and the absorption by the canopy is compensated for by the scattering from the vegetation. At shallower (more oblique) look angles, the scattering from the plant dominates. It appears that the scattering from the cobs has a negligible effect.

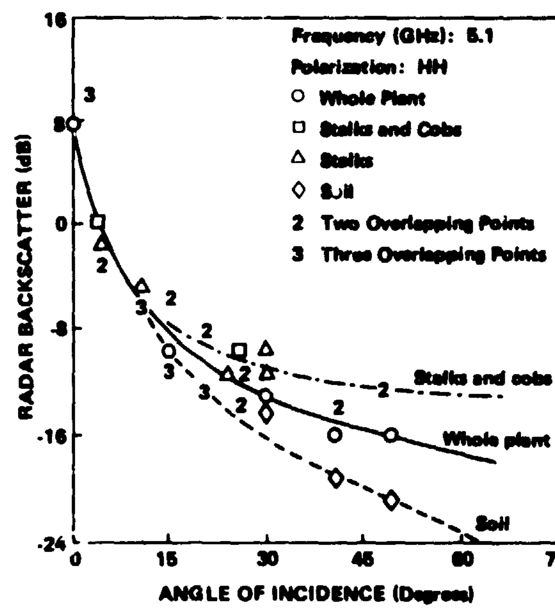


Figure 21.- Radar backscatter from three stages of growth of a corn field. (Whole plant is a fully mature crop; stalks and cobs resulted from stripping of leaves; and soil resulted from cutting and removing stalks.)

In the past year, the first radiometric observations at wavelengths longer than 21 cm were reported. They were at wavelengths of about 50 cm and are from test sites in California and Maryland. As expected, the longer wavelengths showed

a greater soil moisture sampling depth and less sensitivity to surface roughness or vegetation. The surprising and disappointing result is that there appears to be less sensitivity to soil moisture variations at the longer wavelengths for smooth surfaces.

4.5.3 Seasat Data Utility

Analysis of SAR data for several Seasat scenes has displayed the increased soil moisture effects resulting from rains. An example is the scene of Waterloo, Iowa, acquired on August 20, 1978, figure 22. The right hand side contains the rainfall observations for this area on August 19. By comparing the rainfall map with the SAR scene, it is clear that the rain of August 19 is the cause of the increased brightness which is seen in the eastern portion of the SAR scene. Two major points of interest arise from this interpretation. First, although the area around Grundy Center received only a trace of rain, it appears as a region of brighter tone on the SAR image. This indicates the sensitivity to even small increases in soil moisture. Secondly, the area around Marshalltown, Iowa, also shows up as a region of brighter tone; however, no rain was reported for this area. This apparent discrepancy can be resolved by concluding that the rain event occurred between the rain gauges and, thus, was not recorded in the ground-based observations. This indicated the potential for increased spatial coverage of rainfall events that may be obtained with a spaceborne SAR.

The high spatial resolution available with the SAR provides the opportunity to compare the satellite observations directly with ground measurements. Figure 23 is a comparison of the digitally processed SAR data with ground measurements of soil moisture for bare soil, alfalfa, and sorghum (milo) fields in the Oklahoma panhandle. The backscatter from corn, either cut or standing, was much stronger and showed no sensitivity to soil moisture. This strong correlation

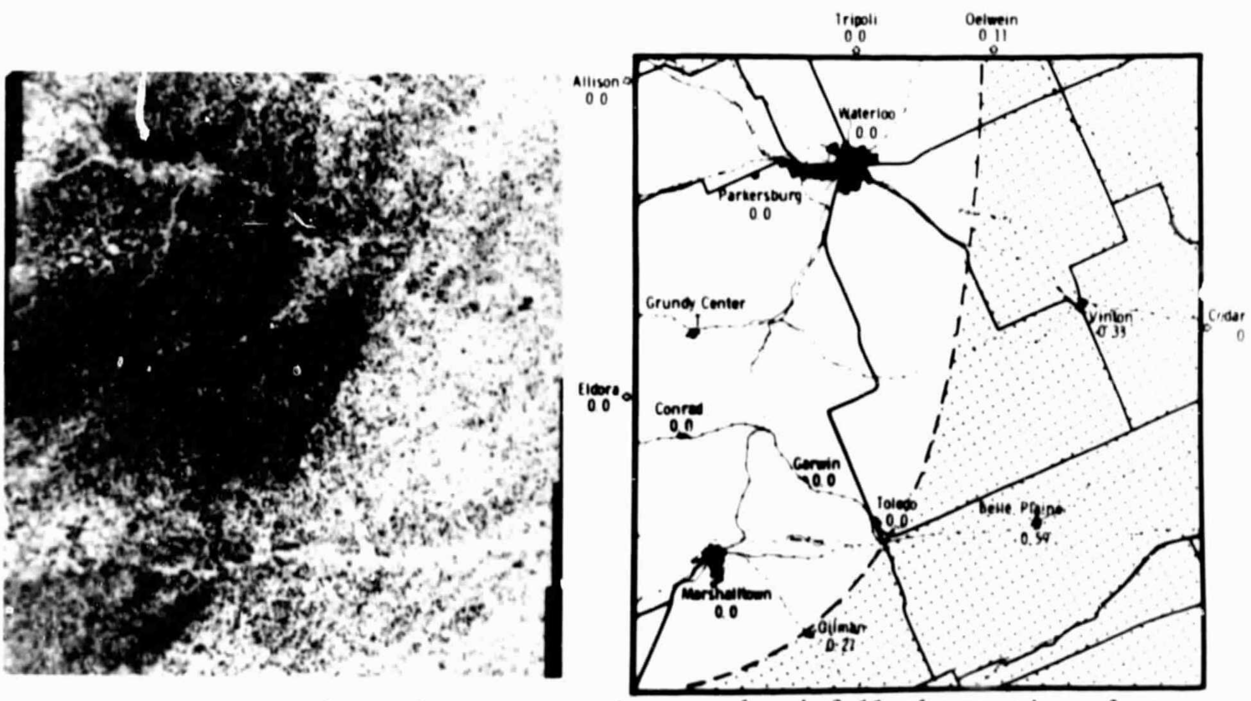


Figure 22.- Comparison of Seasat SAR image and rainfall observations from Waterloo, Iowa, area. (Rainfall indicated is in inches.)

between the satellite backscatter observations and the surface soil moisture measurements is very encouraging. However, the strong backscatter from corn and the inherent sensitivity to surface slope and roughness indicate the need for knowledge of the surface conditions before quantitative estimates of soil moisture can be inferred.

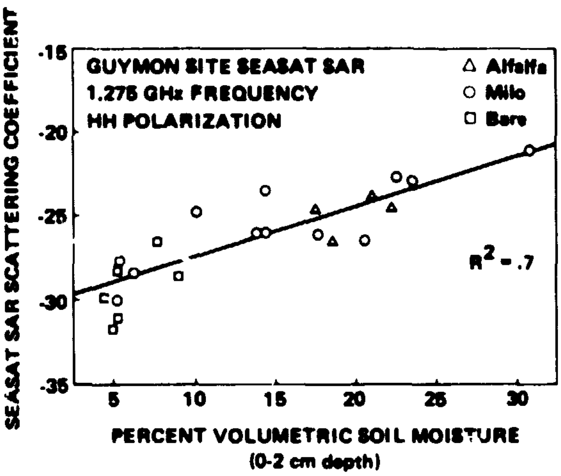


Figure 23.- Seasat SAR backscatter versus ground measurements of soil moisture for individual fields.

4.5.4 In Situ Sensor Development

The development of an in situ nuclear magnetic resonance sensor that is capable of measuring soil moisture quickly and in a continuous manner has progressed rapidly during FY 1982. Southwest Research Institute of San Antonio, Texas, is in the final stage of assembling the instrument.

4.5.5 Profile Moisture Determination

The problem of determining the moisture content in the soil profile has been approached, using the statistical method of studying the correlation between the moisture content in surface layer and that in the total profile. For data obtained at Colby, Kansas, the correlation between the 0-5 cm layer and the 0-45 cm layer for corn fields was found to be 0.75; while this is not sufficient for a predictive relation, it does indicate a relationship between the moisture contents in the two layers. Presently, soil physics models are being studied to determine how knowledge of the surface layer moisture can be exploited to obtain information on the moisture content in the entire profile of interest. These methods are concentrating on using remotely sensed data about the surface to determine the moisture fluxes at the surface that can be used in moisture budgeting procedures for determining the moisture storage.

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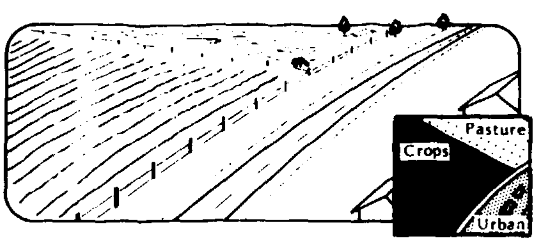
4.6 DOMESTIC CROPS AND LAND COVER

The DC/LC crop acreage objectives are to improve state and substate crop acreage estimates by integrating Landsat data with ground data from the existing USDA program and to evaluate the effectiveness of alternative procedures. The land cover objectives are to explore methods for meeting USDA needs for land cover inventories, land use change estimates, and mapping products of land cover.

This project is managed by the USDA Statistical Reporting Service (SRS) with support from NASA. Major crop estimates are being addressed first in the U.S. Great Plains for wheat and in the U.S. Corn Belt for corn and soybeans. Plans call for adding two states each year to the applied crop estimation research.

DOMESTIC CROPS AND LAND COVER

Directed at automatic classification and estimation of land cover with emphasis on major crops, this project uses Landsat and advanced sensor data to improve accuracy of data classification on the local level.



4.6.1 Technical Objectives

Technical objectives during FY 1982 focused on the following:

- Developing, testing, and evaluating operational procedures for estimating the acreages of major crops over large areas, such as a state.
- Completing the first study to evaluate SRS methodology to estimate land use/land cover.
- Developing procedures for estimating crops in small areas such as counties.
- Evaluating new sensors for their potential ability to distinguish crop and land cover classes.

4.6.2 Crop Acreage Estimation Over Large Areas

For the 1982 crop year, estimates of harvested winter wheat acreages in three states (Kansas, Colorado, and Oklahoma) and planted corn and soybean acreages in two states (Iowa and Illinois) were calculated by combining available Landsat data with ground data. The ground data consisted of information on field locations and acreages derived from the USDA/SRS June Enumerative Survey (JES). Slight changes to standard JES procedures were required to identify areas of wasteland within cropped fields and to extract the reported information in a unique, field-identified format.

This joint use of data from Landsat and from JES sample units requires accurate determination of sample-unit locations within the Landsat scene. Location to the nearest one-half pixel is required. During FY 1982, the Automatic Segment Matching Algorithm (ASMA) for automatically positioning JES sample units in Landsat data was tested. In the ASMA test, the algorithm eliminated manual shifting procedures for approximately three-fourths of the sample units. In the event of algorithm failure, the ASMA flags the sample unit that it is to be manually shifted. During FY 1982, the ASMA computer program was used in the five-state crop-acreage estimation work.

4.6.3 Land Use/Land Cover Estimation

During FY 1981-1982, a state-level land cover study was conducted in Kansas. All land within the 435 June Enumerative sample segments were

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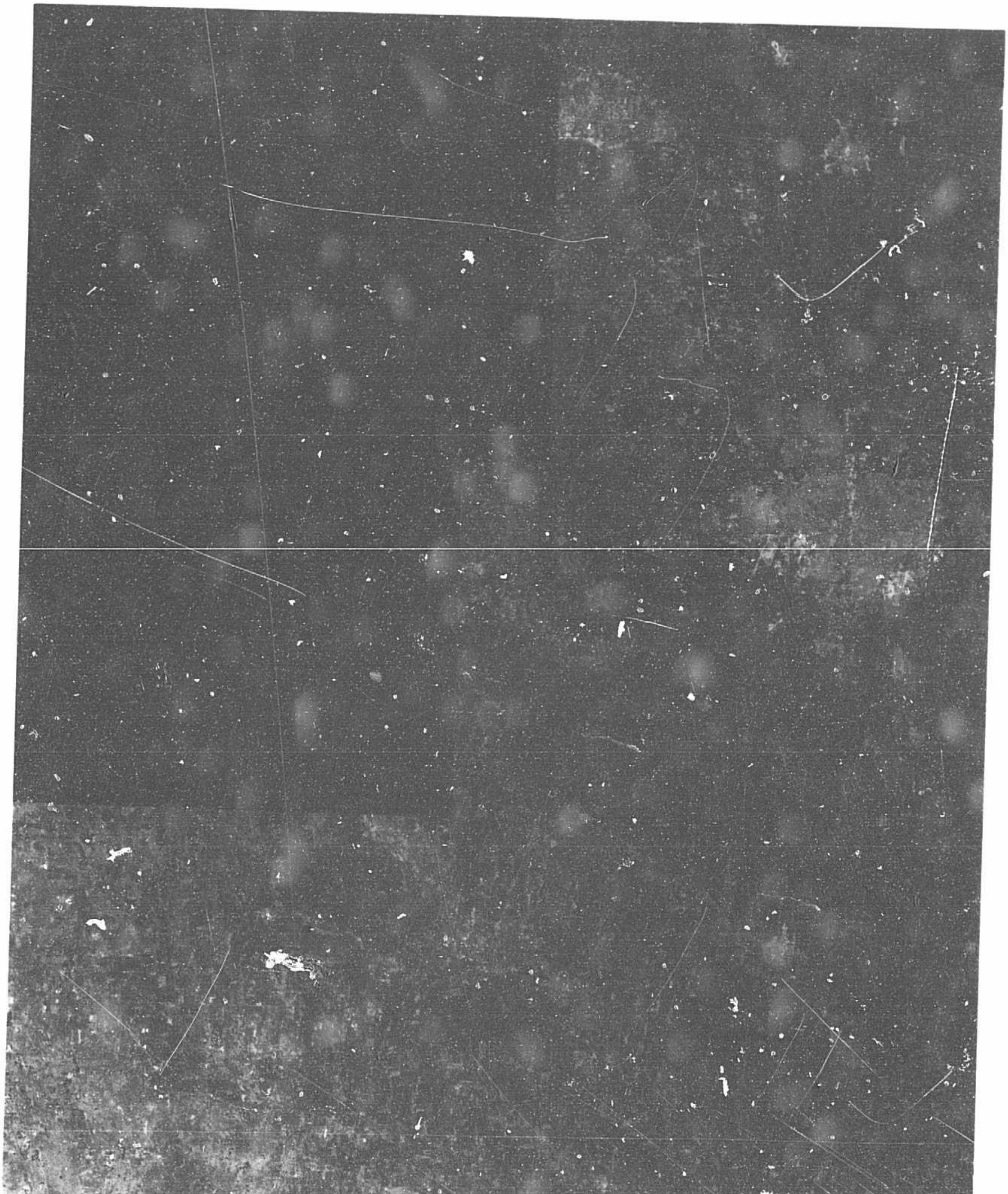

Figure 24.- Classification map of portions of Harper, Sumner, Sedgwick, and Harvey Counties, Kansas. (Seventeen land cover types are displayed).

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enumerated into 17 land cover types. These were used to develop a land cover classification for the entire state. Predictive relationships between the ground and classified data were used to produce state-level, statistically based, acreage estimates for these cover types. Regional land cover maps and associated acreage estimates were also produced. Figure 24 is a resultant generalized land cover map of Harper, Sumner, Sedgwick and Harvey Counties. Wichita, Kansas, is easily discerned toward the top in this figure.

Techniques for using Landsat digital data to determine changes in land use were also investigated in FY 1982. The techniques developed use multidate Landsat data and are designed to work in a range of environments. Testing of these procedures has been conducted in east central Louisiana, where cropland is replacing large expanses of bottomland hardwood forests, and in southwest Kansas, where vast acreages of rangeland are being converted to irrigated cropland. Figure 25 illustrates the change detection techniques applied in southwest Kansas.

The change detection techniques produce land use and land change information which can be put in a geographical data base. This was accomplished for the USDA/SRS area sampling frame units in the Louisiana and Kansas study sites. Figure 26 illustrates how change detection techniques can be used as a potential aid in updating USDA/SRS area sampling frames in Concordia Parish, Louisiana.

4.6.4 Crop Acreage Estimation at the County Level

During Fy 1982, two studies of crop acreage estimation at the county level were conducted. One of these studies was a comparison of two procedures, one of which was selected for future USDA/SRS Landsat projects.

The second study investigated the effect of the classification procedure on the relationship between a crop's Landsat classification result and its ground area. This second study was performed by analyzing simulations of JES ground data and accompanying Landsat data. As a part of this study, basic theory for

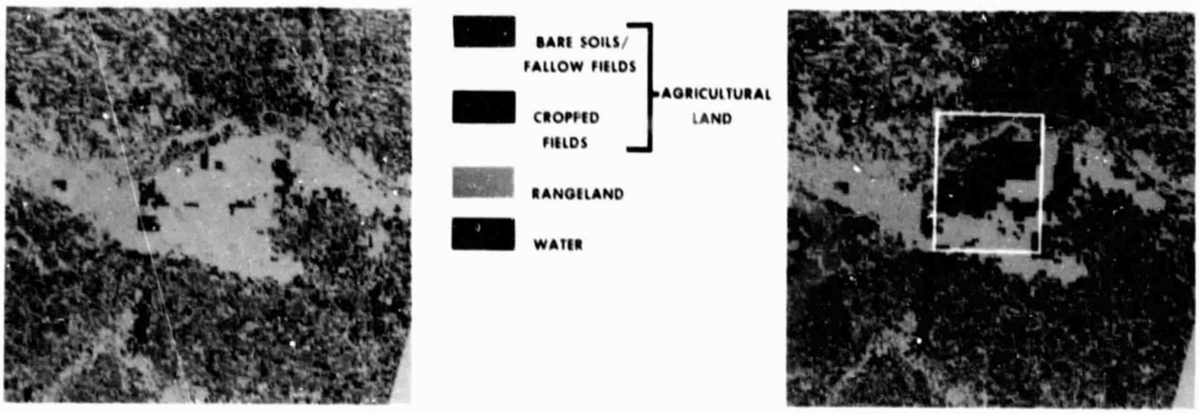


Figure 25.- Illustration of land use changes in southwest Kansas. (The increase in the number of circularly irrigated fields is highlighted by the region in the rectangle.)

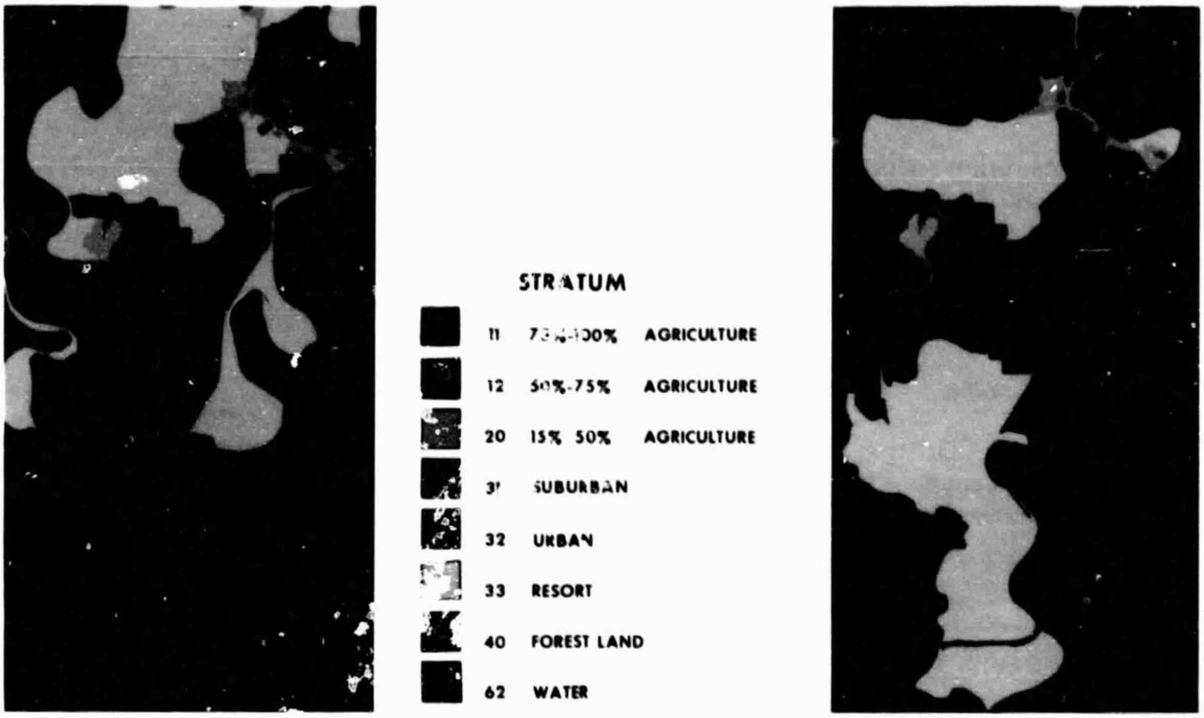


Figure 26.- Updated area sampling frame for Concordia Parish, Louisiana, using change detection techniques. (The increase from left image to right image in agricultural use is dramatic.)

designing classification procedures which are appropriate for crop acreage estimation at the county level has been derived.

4.6.5 Evaluation of New Sensor Data

Several FY 1982 studies investigated the potential ability of new sensors to distinguish crop and land cover classes. These studies evaluated aircraft SAR and TMS data.

The evaluation and analysis of SAR data were conducted using X-band, aircraft SAR over: a Dade County, Florida, truck garden (row crops) area; a paddy rice area in Acadia Parish, Louisiana; and a forested area in Kershaw County, South Carolina. The SAR data was digitized and then processed separately and in combination with Landsat MSS data.

DATA	ACCURACY
SAR and MSS	81%
SAR alone	59%
MSS alone	72%

The results above indicate that classification, using X-band SAR plus bands 5 and 7 of Landsat MSS, gives significantly better results than SAR or MSS alone for the South Carolina study area.

Preliminary results from the Dade County data set indicated significant signature differences were present in the multipass data in which one flight pass was orthogonal to the other. This suggests the usefulness of multipass data for the detection of row crops.

In Acadia Parish, surface wetness, such as in rice fields flooded with water, was detected using SAR polarization data.

The TMS study attempted to relate forest canopy closure to TMS spectral values. The study site was in the San Juan National Forest, Colorado. The vegetation present was primarily aspen and ponderosa pine.

The following observations were made:

- As forest canopy closure increased, the response in all TMS spectral bands decreased.

- The high spectral reflectivity of the background (such as dry soil or senescing grasses) probably contributed significantly to the response in all bands.

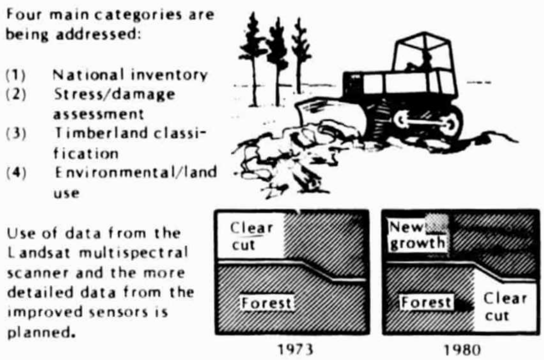
- Out of the seven TMS bands, the spectral response in band 5 was probably most influenced by forest canopy closure.

An equation for predicting forest canopy closure from the spectral response in TMS band 5 was developed.

4.7 RENEWABLE RESOURCES INVENTORY

The objectives of the RRI project are the development and implementation, in the USDA Forest Service, of new remote sensing technology which will offer capabilities in support of the national renewable resource assessment process. The USDA Forest Service will be the user of the technologies developed under the RRI project. The Forest Service is the management agency in this project.

RENEWABLE RESOURCES INVENTORY



4.7.1 Technical Objectives

The particular technical objectives in FY 1982 were focused on:

- Improving methods for the collection, display, and use of resource information for forest management and planning.
- Evaluating Landsat technology as a tool for supporting multiresource inventories and forest planning.
- Demonstrating the capability to monitor, classify, and measure disturbances and changes in forests and rangeland.
- Evaluating TMS.
- Improving the capability to map and characterize natural and managed wildlife habitats.

4.7.2 Forest Management and Landsat MSS Evaluation

The Phase II, Multiresource Inventory Methods Pilot Test demonstration on the usefulness of an interactive computer geographic information system with an interactive data base for operational and planning activities at the district level of the National Forest System was completed. Specifically, this study used state-of-the-art computing systems to demonstrate the incorporation of maps, aerial photographs, and Landsat-derived polygon and attribute data in a data base; the manipulating of data to create new information; and the display of various data layers. This demonstration, using data from the Mancos District of the San Juan National Forest, Colorado, brought together many of the elements of other RRI tasks and demonstrated that they can be used as a tool for forest management.

Four years of investigation have been completed on the use of Landsat and geographic information systems for forest policy analysis with the State of California. After completing a statewide land cover map in 1979, RRI personnel examined in detail five key forested regions of the state, using supervised computer classification and data base modeling techniques. The results of this work have led to changes in the forest management policy in California.

4.7.3 Change Detection and Disturbance Monitoring

Evaluations, using Landsat MSS data demonstrating the capability to monitor disturbance and change, were continued in 1982. Results clearly demonstrated that simple computer-aided analysis of Landsat MSS data is capable of

accurately delineating healthy forest and heavily defoliated forest. Results also demonstrated that computer-aided analysis of Landsat MSS data can delineate areas of change in a forest, especially major changes such as logging, fire, avalanche, etc., as well as areas of no change, thereby, reducing the resources required for more detailed analysis of changed areas.

4.7.4 TMS Evaluation

Several tests have been conducted demonstrating the usefulness of TMS data in forest management. The TMS is an airborne, commercially available, scanner with spectral bands very similar to those of the Landsat-4 TM. A test over the Pearl River site in Mississippi indicates that land cover for hay, old fields, marsh, river bottom forest, mixed forest, pine forest, and water can each be computer-classified with an overall accuracy of 92 percent, using differing subsets of TMS channels. These results offer encouraging prospects for use of TM data to meet RRI objectives.

4.7.5 Wildlife Habitat Mapping

A test was conducted to evaluate the utility of single-date categorized Landsat data as a source of land cover information in assessing elk habitat quality.

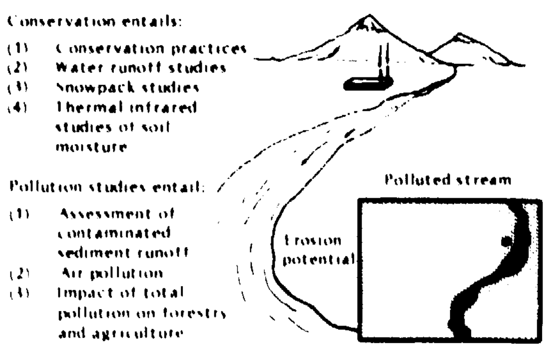
4.8 CONSERVATION AND POLLUTION

The conservation assessment portion of the C/P project addresses applications in three areas: inventory of conservation practices, estimation of water runoff using hydrologic models, and determination of the physical characteristics of snowpacks.

The pollution portion of the C/P project will provide an assessment of conservation practices through the use of remote sensing techniques to assess quantitatively: sediment runoff, gaseous and particulate air pollutants, and the impacts of these factors on agricultural and forestry resources.

The USDA/ARS manages the C/P project with support from NASA and NOAA.

CONSERVATION AND POLLUTION



4.8.1 Technical Objectives

Specific FY 1982 technical objectives focused on the following:

- Determining the suitability of present and planned remote sensing data for use in existing hydrologic models and developing new models or components to incorporate remotely sensed data for water resources management.
- Using available visible, near-infrared, thermal-infrared, and microwave satellite data in conjunction with radiometric measurements from ground-based and aircraft systems to determine the effects of snow physical properties and changes in condition.
- Studying the potential use of Landsat MSS data as input to pollution models, and evaluating methods of remotely measuring atmospheric oxidants in areas where impact on vegetation is suspected.

4.8.2 Water Resources Management

Research has shown that remotely sensed estimates of the surface soil moisture would greatly improve estimates of the disposition of precipitation. Some precipitation enters the soil and recharges the soil moisture reservoir. That which exceeds the infiltration capacity becomes surface runoff.

This past year was devoted to the development of a usable infiltration model that could be defined in terms of surface soil moisture and soil parameters that can be derived from available USDA maps. An equation was used to generate a synthetic infiltration series for an array of conditions that could be encountered in the field. Experiments were successfully conducted using this equation to simulate infiltration by relating cumulative infiltration capacity to the amount of storage used.

The National Weather Service River Forecast System (NWSRFS) model and the associated National Weather Service snowmelt model are currently being modified to accept remote sensing input, namely, snow cover extent, surface water extent, snow water equivalent, and

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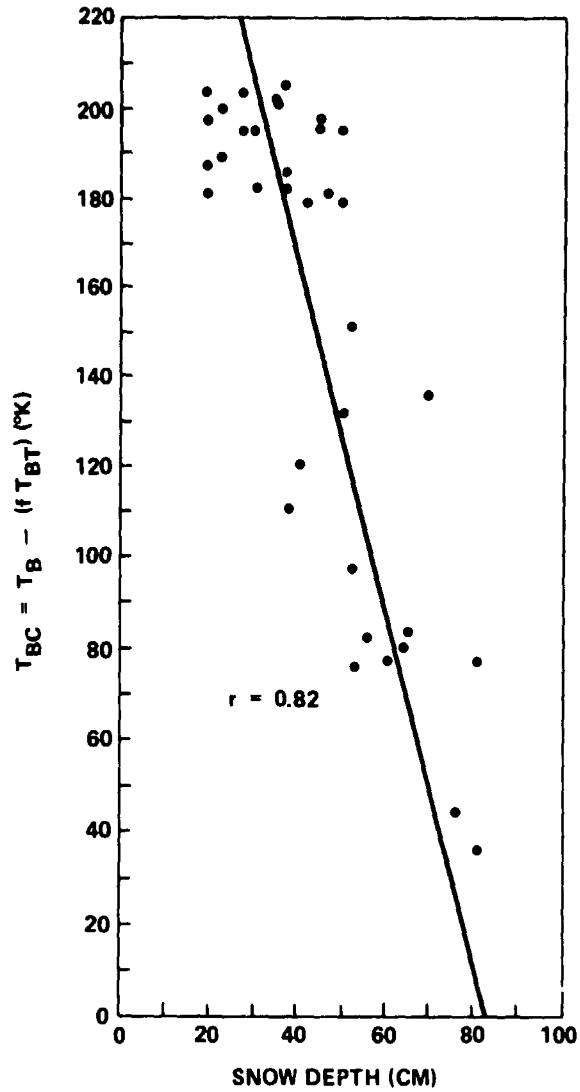
soil moisture. Major emphasis, thus far, has been on development of a technique for combining measurements from different sources (point, aircraft, spacecraft) to produce an areal average value for input to the models. This technique is essential for incorporating both conventional and remotely sensed data in the modified models. Testing of the technique and modified models will be conducted on watersheds to be selected.

4.8.3 Snowpack Studies

Field experiments were conducted in northern Vermont and the U.S. Great Plains to develop techniques for remotely measuring hydrologically important snowpack properties. Truck-mounted and airborne microwave radiometers, operating at frequencies from 6 to 37 GHz (wavelengths from 5 to 0.8 cm), were used. These studies indicate the potential usefulness of microwave emission measurements in distinguishing between wet and dry snowpacks over large areas and in characterizing the amount of snow present. The new data confirm and expand results obtained from radiative transfer modeling and from similar experiments performed in the Colorado Rocky Mountains during previous winters. The field data also suggest that the existence, spacing, and thickness of ice layers strongly modulate the microwave signature of snowpacks.

In other snow research, investigators developed a simple model to remove the effects of forest cover from Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) data of snow fields under a Michigan forest (see fig. 27). This work extended microwave remote sensing techniques to more heterogeneous snow-covered areas in that previous studies have been limited to large uniform regions like the U.S. Northern Great Plains. The best correlations between microwave response and snow depth were obtained at the SMMR



LEGEND	
T_B	= BRIGHTNESS TEMPERATURE OF CELL
T_{BT}	= ESTIMATED BRIGHTNESS TEMPERATURE OF TREES
f	= PERCENT FOREST COVER IN CELL
T_{BC}	= RESIDUAL BRIGHTNESS TEMPERATURE OF SNOW IN CELL

Figure 27.- Snow depth versus Nimbus-7 SMMR microwave brightness temperature corrected for forest cover effects.

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frequency of 37 GHz; lower frequencies showed increased effects of the underlying soil moisture.

4.8.4 Air Pollution and Vegetation Impact

Research continued on the measurement and analysis of field reflectance spectra (500-2500 nm) of snap bean plants receiving various low levels of ozone (O_3) throughout the growing season. Snap beans were selected last year as a good test species for injury induced by pollutants, particularly ozone. The data for the past 2 years were compared, and the results suggest the following (see fig. 28).

- The near-infrared inflectance increases were not a good indicator of O_3 damage because of the high variability of the measurements.

- The red region of the spectrum (600 to 700 nm) was a good measure of O_3 damage.

- The problem noted with O_3-induced changes in red reflectance is absent in the changes seen in the water absorption region of the near-infrared.

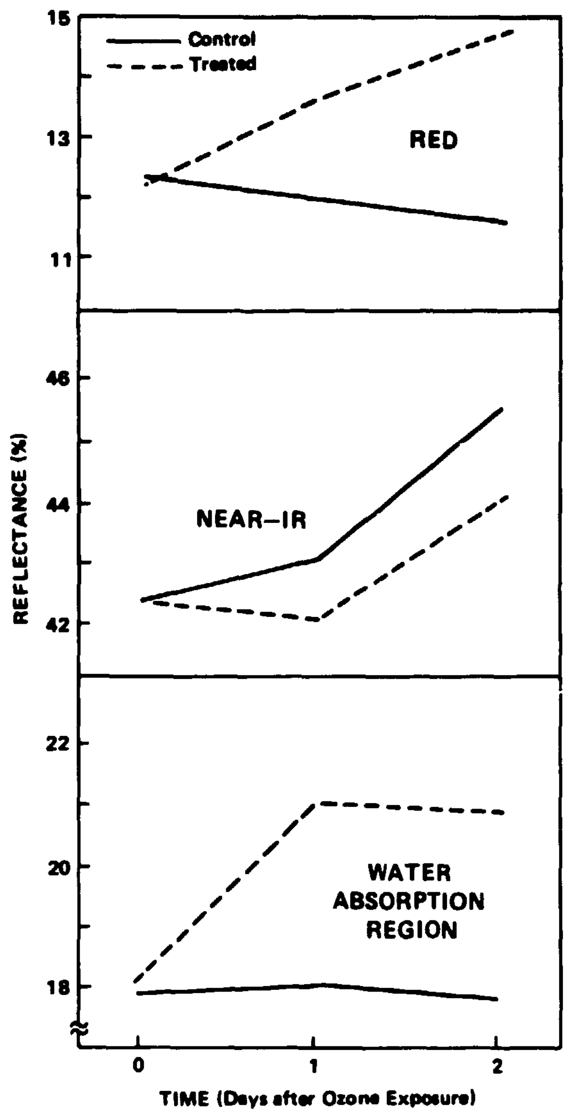

Figure 28.- Reflectance changes in snap bean plants observed one and two days after exposure to 60 ppb ozone for 2 hours. (The "0" values are averages of reflectance measurements made immediately prior to exposure. Each point is the average of five separate experiments.)

APPENDIX A

AgRISTARS MANAGEMENT AND ORGANIZATION

1. INTRODUCTION

The program scope of AgRISTARS specifically addresses the seven information requirements identified by the Secretary of Agriculture.[3] It is structured into projects designed to conduct research, develop, test, and evaluate the various applications of aerospace technology. These projects are designed to support a decision regarding the routine use of remote sensing technology by USDA.

2. RESPONSIBILITIES

The organization and management philosophy recognizes that each involved Government agency enters into an agreement to support remote sensing research which will address the information requirements defined by the USDA. Each Government agency budgets, manages, and maintains control of the resources necessary to meet its own responsibilities as jointly agreed upon (see fig. A-1).

3. JOINT MANAGEMENT STRUCTURE/ORGANIZATION

The program utilizes the matrix management system. There are eight major projects, each having a number of tasks assigned to various line organizations of the participating agencies. Each of the eight projects has a project manager who reports to a Program Management Team (PMT). The PMT, in turn, takes its direction and guidance from the Interagencv Coordinating Committee (ICC). As viewed in figure A-2, the functional relationships are structured into a three-level management system, each having distinct responsibilities.

3.1 INTERAGENCY POLICY BOARD

The Interagency Policy Board (IPB), chaired by USDA, is a joint agency group of policy-level officials at the Assistant Secretary or equivalent level. It is responsible for approving major interagency agreements and establishing basic policies and guidelines for the program.

3.2 INTERAGENCY COORDINATING COMMITTEE (LEVEL 1)

The ICC is comprised of membership from USDA, NASA, USDC, USDI, and AID. It is chaired by the USDA and is responsible for: approving AgRISTARS program objectives and establishing priorities; approving the AgRISTARS Program Plan; assessing progress, identifying problems, and developing corrective actions; and coordinating the use of resources assigned to the program.

3.3 PROGRAM MANAGEMENT TEAM (LEVEL 2)

The PMT represents a joint approach to management which provides participation, project integration, and needed visibility by all participants and assures full responsiveness to USDA information requirements.

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[3] Joint Program of Research and Development of Uses of Aerospace Technology for Agricultural Programs, February 1978.

USDA

- DEFINITION OF USDA INFORMATION REQUIREMENTS.
- YIELD MODEL RESEARCH, DEVELOPMENT, AND TESTING (RD&T) AND APPLICATIONS.
- RD&T – APPLICATIONS ANALYSIS FOR AREA, YIELD, AND PRODUCTION ESTIMATION.
- DEVELOPMENT OF AGRONOMIC/ANCILLARY DATA BASE.
- USER EVALUATION.
- GROUND DATA COLLECTION.
- RD&T AND APPLICATIONS FOR CROP WEATHER ASSESSMENTS.[1]
- RD&T AND APPLICATIONS FOR EW/CCA ANALYSIS.
- RD&T AND APPLICATIONS FOR RRI ANALYSIS.
- RD&T AND APPLICATIONS FOR LAND USE, PRODUCTIVITY AND C/P ANALYSIS.
- RD&T FOR SOIL MOISTURE MEASURING TECHNIQUES.
- LARGE-SCALE APPLICATIONS TESTS.

NASA

- RD&T FOR FOREIGN CROP AREA ESTIMATION.
- RD&T FOR COMBINING AREA AND YIELD ESTIMATES FOR FOREIGN CROP PRODUCTION.
- FIELD RESEARCH.
- LANDSAT DATA ACQUISITION.
- RD&T – SPECTRAL INPUTS TO YIELD MODELS.
- RD&T – SPECTRAL INPUTS TO QUANTITATIVE EW/CCA.
- RD&T FOR SPECTRAL ANALYSIS RELATED TO INVENTORY AND CONDITION ASSESSMENT TECHNIQUES FOR RRI.
- RD&T INVENTORY AND MONITORING TECHNIQUES FOR LAND USE AND C/P.
- RD&T FOR REMOTELY SENSED SOIL MOISTURE MEASURING TECHNIQUES.
- DEFINITION OF REQUIREMENTS FOR FUTURE SENSORS (INCLUDING IN-SITU).

USDC

- METEOROLOGICAL DATA BASE.
- RD&T AND APPLICATIONS OF ENVIRONMENTAL SATELLITE DATA.
- RD&T METEOROLOGICAL YIELD MODELS.
- RD&T WEATHER/CROP ASSESSMENTS.[2]
- RD&T ON USE OF CONVENTIONAL AND SATELLITE-DERIVED METEOROLOGICAL DATA APPLIED TO RRI AND C/P.
- RD&T ON TECHNIQUES FOR DETERMINING SOIL MOISTURE.

USDI

- LANDSAT DATA STORAGE, RETRIEVAL, AND DISSEMINATION.

AID

- EVALUATION OF UTILITY OF RD&T RESULTS FOR APPLICATIONS IN DEVELOPING COUNTRIES.

[1]Primary emphasis is on assessment of crop conditions (e.g., yield, production) using meteorological data as an input to develop needed information.

[2]Primary emphasis is on acquisition and evaluation of meteorological data in terms of its utility for crop condition assessment.

Figure A-1.- AgRISTARS responsibilities of five Government agencies.

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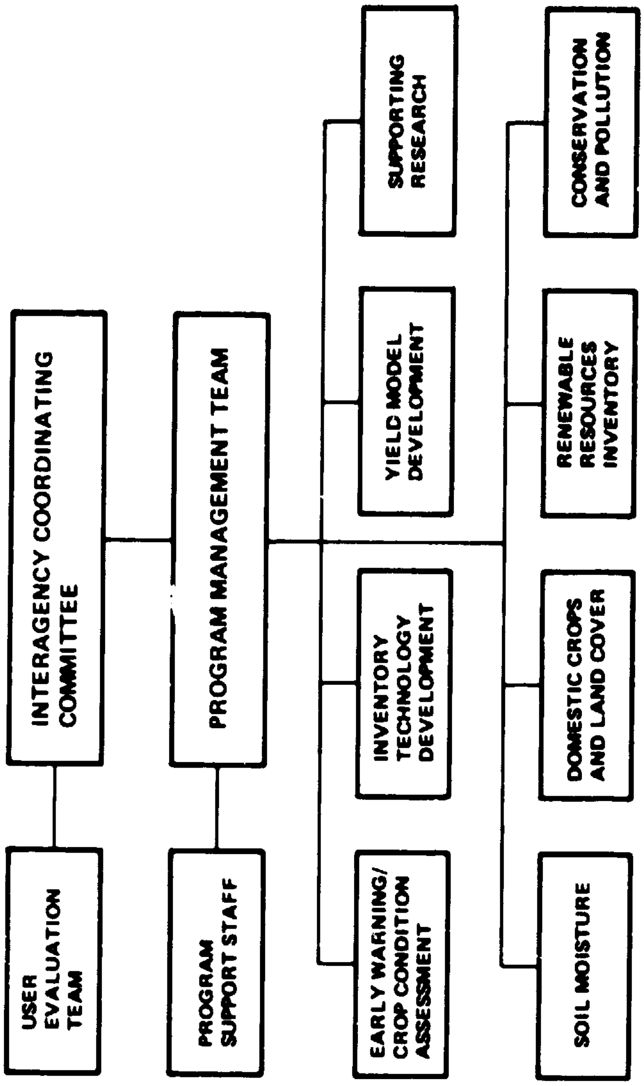

Figure A-2.- Joint agency program management and functional relationships.

The PMT acts as the project change authority for all issues and significant changes affecting specified control milestones and schedules and project goals and objectives.

3.4 PROGRAM SUPPORT STAFF

The Program Support St.-f (PSS) is led by USDA, ha membership from all agencies, and provides staff support to the PMT.

4. PROJECT MANAGERS (LEVEL 3)

Each of the projects is headed by a project manager who was selected from a participating agency, based principally upon considerations of technical expertise and expected levels of agency involvement. The project managers are responsible to the PMT for planning and managing activities within their projects. This includes defining project content, identifying expected products and schedules, assessing status and progress, identifying problems, making change recommendations, planning and defining tasks, and participating with other project managers in the integration of the various projects.

5. REVIEW AND REPORTING

A review and reporting plan has been established to support major program planning and budgetary events.

Each year in the May-June time period, the PMT, project managers, and task managers update each of the project implementation plans to reflect current budgets and the results and recommendations resulting from the various technical reviews.

Internal reviews are held at the various levels of management as required.

6. DOCUMENTATION

All aspects of the program are being documented in full by: reports; technical memoranda and journal articles, as appropriate; press releases; and program progress reports.

7. PARTICIPATING ORGANIZATIONS

Many elements of Government, industry, and the university community are participants in AgRISTARS.

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APPENDIX B

AgRISTARS PROGRAM AND PROGRAM-RELATED DOCUMENTATION

1. GENERAL

This appendix contains a by-project listing of all AgRISTARS program and program-related documentation from program inception through documentation of tasks completed in FY 1982. The listing provided has been further subdivided within each project into areas of plans, reports, procedures, etc., to facilitate easy retrieval of desired documentation.

2. REQUESTING DOCUMENTS

2.1 AgRISTARS DOCUMENTS WITH NTIS NUMBERS

Reproduction of all AgRISTARS documents with NTIS numbers should be available by writing:

National Technical Information Services
5285 Port Royal Road
Springfield, Virginia 22161

Otherwise, request documents according to instructions in sections 2.2 and 2.3.

2.2 CONTROLLED DOCUMENTS

Documents which carry an AgRISTARS control number may be obtained from NASA/JSC by either telephone or mail request. Address requests to:

Lyndon B. Johnson Space Center
SK - Documentation Manager
Houston, Texas 77058
Telephone 713-483-4776

2.3 UNNUMBERED DOCUMENTS (00900 SERIES AND PRESENTATIONS)

Requests for material within this area will be honored based upon availability of data. Requests should be made to:

Lyndon B. Johnson Space Center
(Appropriate Project)
SK - Program Support Staff
Houston, Texas 77058
Telephone 713-483-254[illegible]

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PROJECT: AgRISTARS PROGRAM DOCUMENTATION (AP) — Reports - 00400

0-01. AgRISTARS Annual Report. AP-J0-04111, 1980. NTIS: 82N23609.

0-02. AgRISTARS Documents Tracking List Report. AP-L1-04116, First Edition, Feb. 1981.

0-03. AgRISTARS Documents Tracking List Report. AP-L1-04116, Second Edition (February, March, April, May 1981), June 1981.

0-04. AgRISTARS Documents Tracking List Report. AP-L1-04116, Third Edition (Through September 1981).

0-05. AgRISTARS Documents Tracking List Report. AP-L2-04116, Fourth Edition (Through March 1982).

0-06. AgRISTARS Documents Tracking List Report. AP-L2-04116, Fifth Edition (Through June 1982).

0-07. AgRISTARS Documents Tracking List Report. AP-L2-04116, Sixth Edition (Through December 1982).

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